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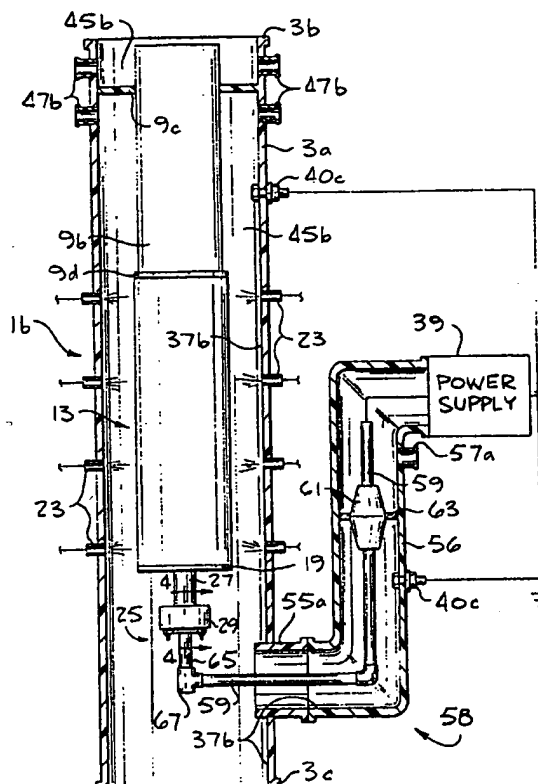As rescanning documents *will not* correct images, please do not report the images to the Image Problem Mailbox.

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: WET ELECTROSTATIC FILTRATION PROCESS AND APPARATUS FOR CLEANING A GAS STREAM

(57) Abstract

The present invention relates to a gas cleaning process and apparatus for removing solid and liquid aerosols entrained in a gas stream. The gas to be treated is passed through a wetted, electrostatically charged filter media. In accordance with a preferred embodiment of the present invention, the polarity of the electrostatic charge on the filter media is selected to enhance the removal of captured solid particles from the filter media. The apparatus is readily adaptable to a modular gas cleaning system configuration wherein varying numbers of the apparatus may be operated in parallel to provide a gas cleaning system of any desired gas flow capacity.

WET ELECTROSTATIC FILTRATION PROCESS AND APPARATUS
FOR CLEANING A GAS STREAM

BACKGROUND OF THE INVENTION

The present invention relates to a gas cleaning

5   process and apparatus for removing suspensions of solid
and/or liquid particles (i.e., aerosols) entrained in a
gas stream which utilizes a wetted, electrostatically
charged filter media. The present invention is
particularly suited for cleaning gaseous effluents

10   emitted from various industrial installations such as
incinerators, calciners, utility boilers, sulfonation
operations and wood products manufacture facilities,
among many others.

Electrostatic precipitation is a widely used

15   technique for separating solid and liquid aerosols from
gas streams. Electrostatic precipitators are
characterized by at least one ionizing electrode (e.g., a
wire, sharp-edged rod or other conducting member having a
small radius of curvature) maintained at high electric

20   potential and spaced from one or more ground or
precipitating electrodes of relatively large surface
area. Particles entrained in the gas to be treated are
charged as the gas is forced to pass through the limited
current discharge (i.e., corona) between the ionizing and

25   precipitating electrodes. The electric field drives the
charged particles to the collecting region of the
apparatus where they are discharged and precipitated on
the surface of the precipitating electrode.

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The collecting surfaces of an electrostatic precipitator must be freed of precipitated material from time to time in order to maintain the desired collection efficiency. As the aerosol load in the gas to be treated

5   increases, more frequent cleaning of the collecting surfaces of the precipitator is necessary. If the particles being collected are essentially dry, removal of precipitated material can be achieved by rapping or shaking the precipitating electrodes. In applications

10   where the particles being collected are wet and/or tacky, a wet electrostatic precipitator design may be employed. In wet electrostatic precipitators, the collecting surface of the precipitating electrodes is a liquid film. The liquid film, usually aqueous, may be provided by

15   precipitation of droplets entrained in the gas being treated and/or by irrigating the precipitating electrodes with a liquid spray. During operation, the film of liquid continuously drains from the precipitating electrodes of a wet electrostatic precipitator, thereby

20   removing collected solids which would otherwise tend to accumulate. Although wet electrostatic precipitators are capable of achieving high collection efficiencies, even with respect to smaller (e.g., submicron) diameter particles, the associated capital and operating costs are

25   often prohibitive.

Cloth bags, commonly referred to as baghouse filters, are used to remove solid particles entrained in dry gas streams. As dust-laden gas flows into the filter bag, entrained solids collect on the bag and clean gas

30   passes through. Periodically, the collected material is dislodged from the bag by mechanically shaking the bag or by flexing the bag with a reverse pulse of compressed

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air. Baghouses are simple and relatively inexpensive to
operate and can achieve high collection efficiencies.
Unfortunately, baghouses are not suited for cleaning gas
streams having a high liquids content and/or containing
5   tacky solids since it is difficult to remove collected
material from the bags. Moreover, in some designs, it
may be necessary to interrupt the gas cleaning operation
while collected material is being removed from the filter
bags.
10   Venturi and other types of scrubbers can be used to
remove liquid particles and tacky solids from gas
streams. However, to achieve high collection
efficiencies, especially with respect to smaller
particles, high pressure drops must be used leading to
15   increased operating cost.
        Therefore, there remains a need for a system for
continuous, efficient cleaning of gaseous, industrial
effluents capable of achieving a high degree of removal
of solid and liquid aerosols entrained in the gas.

20   SUMMARY OF THE INVENTION
        Among the objects of the present invention,
therefore, are the provision of a process and apparatus
for removing solid and liquid aerosols entrained in a gas
stream; the provision of such a process and apparatus in
25   which collected solids are continuously and effectively
purged so that treatment of the gas may be proceed
uninterrupted; the provision of such a process and
apparatus capable of achieving a high collection
efficiency even under high particle loading conditions;
30   and the provision of such a process and apparatus in

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which the capital and operating costs may be reduced as compared to other gas cleaning systems.

Briefly, therefore, the present invention is directed to a process for treating a gas stream to remove

5   solid or liquid particles entrained in the gas stream. The process comprises providing a substantially electrically isolated, gas-permeable filter element comprising electrically conductive filter media wetted with a liquid. The wetted filter media is

10 electrostatically charged by applying an electric potential to the filter media with respect to ground. The gas stream to be treated is passed through an electric field imposed by a limited current discharge between the electrostatically charged filter media and a

15 ground electrode to induce a charge on particles entrained in the gas having a polarity opposite of the charge on the filter media. The gas stream containing charged particles is then passed through the filter element with a horizontal component of movement, the

20 entrained particles thereby being captured in the wetted filter media to produce a clean gas stream from which entrained particles have been removed. Liquid continuously drains from the wetted filter media under the force of gravity. The draining liquid has a

25 horizontal component of movement through the filter media toward the downstream surface of the filter element relative to the direction of gas flow through the filter element imparted by the gas drag force. As the liquid drains from the wetted filter media, it removes particles

30 captured in the filter media and produces a liquid waste stream exiting the filter element containing the removed particles.

5

        Solid particles captured within the wetted filter
media and the liquid wetting the filter media comprise a
suspension having a zeta potential characterized by a
charge of the same polarity attached to the surface of a
5   predominant number of captured solid particles within the
suspension. In accordance with a preferred embodiment of
the present invention, the polarity of the electric
potential applied to the filter media is selected such
that the filter media has a charge of the same polarity
10   as the zeta potential of the suspension of captured solid
particles in the wetted filter media. This results in
captured solid particles in the suspension being repulsed
from the filter media by electrophoresis and enhances
removal of the captured solid particles from the wetted
15   filter media by the draining liquid.

        The invention is further directed to an apparatus
for treating a gas stream to remove solid or liquid
particles entrained in the gas stream and produce a clean
gas stream from which particles have been removed and a
20   liquid waste stream containing particles removed from the
gas stream. The apparatus comprises a housing having an
inlet for introducing the gas stream into the housing, an
outlet for discharging the clean gas stream from the
housing and a liquid drain port for removing the liquid
25   waste from the housing. A substantially electrically
isolated, gas-permeable filter element comprising
electrically conductive filter media wetted by a liquid
is disposed and oriented within the housing such that the
gas stream introduced into the housing is forced to pass
30   through the filter element with a horizontal component of
movement and liquid continuously drains from the wetted
filter media under the force of gravity to remove

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particles captured in the filter media and produce the
liquid waste stream containing the removed particles.
The apparatus further includes a ground electrode
disposed within the housing and connected to ground, a
5   direct current power supply and means for connecting the
direct current power supply to the filter media and the
ground electrode such that an electric potential is
applied to the filter media with respect to ground to
electrostatically charge the filter media.

10   In accordance with another embodiment, the gas
cleaning apparatus of the present invention comprises a
housing in the form of a vertical cylinder having an
inlet for introducing the gas stream into the housing, an
outlet for discharging the clean gas stream from the

15   housing and a liquid drain port for removing the liquid
waste from the housing. A substantially electrically
isolated, gas-permeable filter element and seal leg
combination is suspended within the housing. The gas-
permeable filter element is in the form of a

20   substantially vertical cylinder and comprises
electrically conductive filter media wetted by a liquid
and supported upon a cylindrical foraminous support. The
filter element is disposed and oriented within the
housing such that the gas stream introduced into the

25   housing is forced to pass through the filter element with
a horizontal component of movement to remove particles
entrained in the gas stream and produce the clean gas
stream and liquid continuously drains from the wetted
filter media under the force of gravity to remove

30   particles captured in the filter media and produce the
liquid waste stream containing the removed particles.
The seal leg comprises a liquid drain conduit and seal

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leg cup. The liquid waste stream is removed from the
filter element through the liquid drain conduit and
collects in the seal leg cup to provide a liquid seal in
the liquid drain conduit and prevent the gas stream

5   introduced into the housing from bypassing the filter
media. The apparatus further comprises means for
contacting the gas stream with a spray of liquid droplets
upstream of the filter element relative to the direction
of gas flow, a ground electrode, a direct current power

10 supply and means for connecting the direct current power
supply to the filter media and the ground electrode such
that an electric potential is applied to the filter media
with respect to ground to electrostatically charge the
filter media. The ground electrode is connected to

15 ground and made integral with the housing such that the
interior surface of the housing serves as the ground
electrode.

       The invention is further directed to a modular gas
cleaning system for treating a gas stream to remove solid

20 or liquid particles entrained in the gas stream and
produce a clean gas stream from which particles have been
removed and a liquid waste stream containing particles
removed from the gas stream. The system comprises at
least one gas cleaning apparatus module comprising a

25 housing, a substantially electrically isolated, gas-
permeable filter element and seal leg combination
suspended within the housing and a ground electrode. The
housing is in the form of a vertical cylinder having an
inlet for introducing the gas stream into the housing, an

30 outlet for discharging the clean gas stream from the
housing and a liquid drain port for removing the liquid
waste from the housing. The gas-permeable filter element

is in the form of a substantially vertical cylinder and comprises electrically conductive filter media wetted by a liquid and supported upon a cylindrical foraminous support. The filter element is disposed and oriented

5   within the housing such that the gas stream introduced into the housing is forced to pass through the filter element with a horizontal component of movement to remove particles entrained in the gas stream and produce the clean gas stream and liquid continuously drains from the

10 wetted filter media under the force of gravity to remove particles captured in the filter media and produce the liquid waste stream containing the removed particles. The seal leg comprises a liquid drain conduit and seal leg cup. The liquid waste stream is removed from the

15 filter element through the liquid drain conduit and collects in the seal leg cup to provide a liquid seal in the liquid drain conduit and prevent the gas stream introduced into the housing from bypassing the filter media. The ground electrode is connected to ground and

20 made integral with the housing such that the interior surface of the housing serves as the ground electrode. The system further comprises means for contacting the gas stream with a spray of liquid droplets upstream of the filter element relative to the direction of gas flow, a

25 direct current power supply and means for connecting the direct current power supply to the filter media and the ground electrode such that an electric potential is applied to the filter media with respect to ground to electrostatically charge the filter media. An intake

30 manifold and a clean gas manifold adapted for connection to at least one gas cleaning apparatus module are connected to the module such that the intake manifold and

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the clean gas manifold are in fluid communication through
the module. The gas stream to be treated is introduced
into the intake manifold and passed through the module
and the clean gas stream from the module is discharged
5   from the system through the clean gas manifold. The
intake manifold serves as a sump for collecting liquid
waste draining from the module.

Other objects and features of this invention will be
in part apparent and in part pointed out hereinafter.

10   BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a fragmentary, longitudinal section of a
gas cleaning apparatus in accordance with the present
invention with portions broken away to show the internal
construction thereof.

15   Fig. 2 is a fragmentary, longitudinal section of a
gas cleaning apparatus in accordance with another
embodiment of the present invention with portions broken
away to show the internal construction thereof.

Fig. 3 is a longitudinal section of a gas cleaning
20   apparatus in accordance with another embodiment of the
present invention.

Fig. 4 is an enlarged section taken in the plane
including line 4--4 in Fig. 3.

Fig. 5 is an elevation and partial schematic of a
25   modular gas cleaning system in accordance with the
present invention with portions broken away to show the
internal construction thereof. The system shown in Fig.
5 includes two gas cleaning apparatus of the type shown
in Fig. 3, one of which is shown in phantom.

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Fig. 6 shows the normalized pressure drop (Co)
plotted as a function of time for the tests conducted in
Example 4.

Corresponding reference characters indicate
corresponding parts throughout the drawings.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In accordance with the present invention, a novel
gas cleaning system for separating solid and liquid
aerosols from a gas stream has been devised. The gas to
be treated is forced to pass through a wetted,
electrostatically charged filter media. The charged
filter media induces a charge of opposite polarity on
particles entrained in the gas. The oppositely charged
particles are attracted to the filter media, greatly
enhancing the particle collection efficiency. Unlike
conventional gas filtration mechanisms (e.g., sieving,
impaction, interception, and diffusion), electrostatic
filtration is capable of efficiently capturing particles
entrained in a gas largely independent of the pore size
and void fraction of the filter media. Thus, the filter
media used in the practice of the present invention may
be constructed so as to have a relatively open structure,
combining a high collection efficiency with a low
pressure drop across the apparatus. The present
invention further provides for regeneration of the
electrostatically charged filter media by continuous
removal of the collected particles. This is achieved by
wetting the filter media with a liquid film which
continuously drains from the filter media under the force
of gravity. The draining liquid removes captured
particles from the structure of the filter media so that

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the pressure drop across the apparatus remains
essentially constant and the gas cleaning operation may
proceed uninterrupted. In accordance with a preferred
embodiment of the present invention described in detail

5   below, the polarity of the charge on the filter media is
selected relative to the zeta potential exhibited by the
suspension of captured solid particles in the liquid
wetting the filter media to further enhance the cleaning
of the filter media by electrophoresis.

10   For a better understanding of the invention,
reference is made to Fig. 1 which shows a fragmentary,
longitudinal section of a gas cleaning apparatus in
accordance with a first embodiment of the present
invention with portions broken away to show the internal

15   construction thereof.

     The apparatus 1 comprises a housing 3 having an
inlet port 5 for introducing the gas to be treated and an
outlet port 7 through which clean, treated gas is
discharged from the apparatus. The outlet port is

20   centrally positioned on the top side of the housing and
is in fluid communication with the interior of the
housing through a clean gas conduit 9 extending into the
housing through a fitting 11 which secures the clean gas
conduit to the top side of the housing.

25   A gas-permeable filter element 13 is disposed and
oriented within housing 3 such that the gas stream
introduced into the housing is forced to pass through the
filter element with a horizontal component of movement.
The direction of gas flow through the housing and filter

30   element is indicated by arrows in Fig. 1. As shown in
Fig. 1, the filter element may be in the form of a
substantially vertical cylinder. Filter element 13

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comprises a layer of electrically conductive filter media
15 wound upon a rigid, cylindrical, foraminous support or
screen 17 fastened between an upper support plate 18 and
a lower support plate 19. Upper support plate 18 has a
5   central bore 20 and filter element 13 is secured within
housing 3 by joining the end of clean gas conduit 9
opposite outlet port 7 to the periphery of the bore in
the upper support plate. Thus, outlet port 7 is in fluid
communication with the interior of filter element 13
10   through clean gas conduit 9. Clean gas conduit 9,
cylindrical support screen 17 and upper and lower support
plates 18 and 19 are made of electrically conductive
material (e.g., stainless steel) such that these
components of the apparatus are electrically connected to
15   filter media 15. In order to ensure that filter media 15
is retained on the cylindrical support and to ease
handling of filter element 13, the filter element may
further comprise a gas-permeable, containment mesh 21
wound around support screen 17 adjacent to the exterior
20   (i.e., upstream) surface of the filter media.
Containment mesh 21 may suitably be constructed of a non-
conductive, corrosive-resistant material such as
fiberglass reinforced plastic (FRP).

Woven or nonwoven metal fibers or woven fabrics
25   comprising carbon or metal-coated polymeric (e.g., nylon)
fibers may serve as electrically conductive filter media
15. An example of a suitable woven, metal-coated fabric
is the product sold under the trademark FLECTRON,
commercially available from Monsanto Company, St. Louis,
30   Missouri, U.S.A. In a preferred embodiment, the
electrically conductive filter media comprises a non-
woven stainless steel wool mat made of fibers having a

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diameter ranging from about 40 μm to about 500 μm. In
another preferred embodiment, the electrically conductive
filter media comprises a co-knit material comprising a
mixture of electrically conductive (e.g. metal) and

5   electrically insulative (e.g., polymeric) fibers. An
example of such a suitable co-knit material is that
commercially available from ACS Industries, Houston,
Texas, U.S.A. under Catalog No. 8TMW11. This co-knit
material is made from a continuous, Alloy 20 stainless

10   steel wire having a diameter of about 280 μm and a woven
TEFLON filament having a fiber diameter of about from
about 15 μm to about 30 μm. In the practice of the
present invention, non-woven metal fiber mats and metal
and polymeric fiber co-knit materials are generally

15   equally preferred for use as the electrically conductive
filter media. However, metal and polymeric fiber co-knit
material may offer pressure drop advantages over metal
fiber mats, especially when fine fiber diameters are
required to achieve the desired particle collection

20   efficiency, and are generally more preferred in corrosive
environments (e.g., treatment of acid mist-containing
effluents) where a material cost advantage may be
realized as compared to a filter media comprised solely
of non-woven, corrosion-resistant, high alloy metal

25   fibers.
        Although the present invention is not limited to a
particular theory, the ability of a co-knit material
comprising electrically conductive and electrically
insulative polymeric (e.g., TEFLON, nylon, etc.) fibers

30   to function effectively despite the presence of
electrically insulative material is perhaps explained by
the fact that during operation of the gas cleaning

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apparatus, the filter media remains wetted by a liquid
film which continuously drains from the wetted filter
media under force of gravity. Although it is well-known
that polymeric materials such as TEFLON are generally

5   excellent electrical insulators under dry conditions,
under the wetted conditions present during practice of
the present invention, the surface of the polymeric
fibers is believed to be electrostatically charged and at
the same applied voltage as the surface of the

10   electrically conductive fiber present in the co-knit
material. Therefore, the electrophoresis mechanism
described in detail below by which captured solid
particles are repulsed from the surface of the filter
media would also assist in cleaning the polymeric fibers.

15   In any event, electrically conductive filter media as
used herein should be understood to include filter media
comprised in whole or in part of electrically insulative
materials which are rendered sufficiently conductive upon
being wetted during operation of the apparatus in

20   accordance with the present invention. Although it is
possible to practice this invention where the filter
media consists solely of electrically insulative
material, it is preferred that the filter media include
at least some electrically conductive material.

25   Since the collection efficiency of the apparatus is
significantly enhanced by electrostatically charging the
filter media, a dense, tightly constructed filter media
may not be necessary to achieve the desired collection
efficiency. Preferably, in order to reduce the pressure

30   drop across the filter, the electrically conductive
filter media is relatively thin and has an open, porous
structure. For example, where a non-woven stainless

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steel wool mat is used as the electrically conductive
filter media, suitable results are achieved if the
stainless steel wool mat is from about 2.5 cm to about 5
cm thick and exhibits a void fraction of at least about
5   80 percent, more preferably at least about 94 percent.
By void fraction, it is meant the difference between 1
and the ratio of the bulk density of the electrically
conductive filter media to the density of the material
(e.g., stainless steel fibers) used to form the filter
10   media.

The filter element may also include means for
controlling reentrainment of draining liquid and solid
particles captured in filter media 15 by the clean gas
stream exiting the interior surface of the filter
15   element. Use of reentrainment control means will be
necessary in most applications in order to minimize the
capital costs. As shown in Fig. 1, the reentrainment
control means may comprise a gas-permeable layer of
fibrous material 22 wound around support screen 17
20   adjacent to the interior (i.e., downstream) surface of
the filter media. Fibrous reentrainment control media
are well known in the mist eliminator art and will
typically have an increased fiber diameter and void
fraction relative to the electrically conductive filter
25   media. An example of a fibrous material suitable for use
as a reentrainment control layer is the wiremesh demister
pads commercially available from ACS Industries, Houston,
Texas, U.S.A. This product is made from knitted
stainless steel wire having a diameter ranging from about
30   250 μm to about 300 μm in corrugated profiles. Suitable
reentrainment control media can be constructed from

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successive layers of this product to obtain a layer of
the desired thickness, typically 0.5 cm to 2.5 cm.

During operation of the apparatus, filter media 15
is wetted by a liquid film which continuously drains from
5   the wetted filter media under force of gravity. The
draining liquid removes particles captured in the filter
media as part of a liquid waste stream. The filter media
may be wetted by droplets of liquid entrained in the gas
to be treated which are subsequently captured in the
10   filter media as the gas flows through the filter element.
Typically, however, the gas to be treated will not have a
liquid loading at its source sufficient to ensure
adequate irrigation of the filter element. Thus, in
order to increase the liquid loading of the gas prior to
15   entering the filter element, the apparatus may include
means for contacting the gas to be treated with a liquid
upstream of the filter element relative to the direction
of gas flow. For example, the gas may be contacted with
a spray of liquid droplets or other gas-liquid contacting
20   apparatus may be used. As shown in Fig. 1, such gas-
liquid contacting means may comprise one or more fogging
nozzles 23 extending through the sides of housing 3 and
in selective fluid communication with a source of liquid
(not shown). Fogging nozzles 23 inject liquid into the
25   housing in the form of a dense fog of droplets and may be
of any suitable design, including single fluid high
pressure nozzles or air atomized nozzles. For reasons of
economy, the liquid supplied to the nozzles for injection
into the housing preferably comprises water such that the
30   filter element is irrigated with an aqueous liquid. In
order to facilitate subsequent capture and removal of the
liquid droplets in the filter media, it is preferred that

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the liquid spray generated by nozzles 23 have a mean

droplet diameter greater than about 20 μm. Although it

is preferred, the gas to be treated need not be contacted

with a liquid spray upstream of the filter element.

5   Thus, rather than being wetted by droplets of liquid

removed from the gas to be treated, the filter media may

be wetted directly.

It should be noted that the electrostatically

charged filter media will induce an opposite charge on

10   liquid droplets issuing from the fogging nozzles as the

droplets entrained in the gas to be treated approach the

filter media. Thus, like solid and liquid particles

present in the gas to be treated at its source, charged

liquid droplets entrained in the gas will be attracted to

15   the filter media, greatly enhancing the wetting of the

filter media and removal of captured particles by the

liquid phase draining from the filter element. It is

believed that the electrostatically charged filter media

increases the impingement of liquid droplets entrained in

20   the gas to be treated and creates a tightly bonded liquid

film enveloping the surfaces of the filter media. As a

result, solid particles entrained in the gas to be

treated cannot easily break this liquid barrier and

contact the fiber surface. In this fashion, the

25   electrostatically charged filter media improves wetting

and cleaning of the filter media and decreases plugging

problems.

A conventional liquid seal leg 25 for allowing

liquid waste drained from the filter media to be removed

30   from the filter element without permitting untreated gas

to bypass the filter media is secured to lower support

plate 19. The seal leg comprises a liquid drain conduit

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27 and a seal leg cup 29 provided with a vent 30 and an
overflow pipe 31 through which the interior of the cup is
in fluid communication with the interior of housing 3.
Lower support plate 19 has a central bore 33 and the

5   upper end of liquid drain conduit 27 is joined to the
periphery of the bore in the lower support plate. The
lower end of the liquid drain conduit extends into seal
leg cup 29 which in turn is secured to the liquid drain
conduit. Thus, the entire filter element and seal leg

10   combination are suspended within housing from clean gas
conduit 9. Liquid waste drains from filter element 13
through liquid drain conduit 27 and collects in seal leg
cup 29, providing a liquid seal in the liquid drain
conduit which prevents incoming gas from bypassing the

15   filter media. Liquid waste overflows the seal leg cup
through overflow pipe 31 and is removed from the
apparatus through a liquid drain port 35 in the bottom of
the housing. In order to prevent untreated gas from
exiting the housing through liquid drain port 35, a

20   conventional liquid level controller may be used to
maintain a quantity of liquid in the bottom of housing 3
which serves as a sump and provides a liquid seal.

The apparatus further comprises a ground electrode
37 disposed within the housing and a high voltage, direct

25   current power supply 39. The ground electrode is
comprised of electrically conductive material and, as
shown in Fig. 1, may comprise a metal screen fixed
adjacent to the interior surface of the lateral sides of
housing 3. Preferably, in order to provide a more

30   uniform voltage gradient and electric field, ground
electrode 37 is at least substantially coextensive with

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the surface of the electrically conductive filter media
and their respective surfaces are uniformly spaced.

The apparatus further includes means for connecting
direct current power supply 39 to filter media 15 and

5   ground electrode 37 such that an electric potential is
applied to the filter media with respect to ground to
electrostatically charge the filter media. The ground
electrode is connected to ground and to one terminal
(positive or negative) of the power supply (i.e., the

10   ground electrode is connected to the grounded terminal of
the power supply). In practice, an earth ground will
usually be employed, although it is not necessary. As
shown in Fig. 1, the electrical connection between the
ground electrode and the power supply may be provided by

15   one or more electrically conductive connectors or lugs 40
extending through the lateral side of housing 3 and
contacting the ground electrode. The other terminal of
the power supply is connected to clean gas conduit 9 such
that an electric potential may be applied to filter media

20   15 with respect to ground. Although clean gas conduit 9,
cylindrical support screen 17 and upper and lower support
plates 18 and 19 were previously described as being made
of metal or other electrically conductive material, it
should be understood that all that is required is an

25   electrical connection (i.e., electrical continuity)
between power supply 39 and filter media 15 and that it
is not necessary that all of these components be made of
electrically conductive material. For example, in the
embodiment shown in Fig. 1, so long as clean gas conduit

30   9 and upper support plate 18 are made of electrically
conductive material and filter media 15 is in contact
with the upper support plate, it is not necessary that

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lower support plate 19 and support screen 17 be
constructed of electrically conductive material.
Instead, these components may be made of FRP or other
cost effective materials.

5   Power supply 39 is similar to that used in
electrostatic precipitators and includes low direct
current automatic voltage control means. As described in
greater detail below, the filter media and the ground
electrode may function as either cathode or anode in the
10   practice of the present invention. Accordingly, the
power supply control circuitry preferably allows the
polarity of the electric potential applied to the filter
media to be selectively reversed from positive to
negative and vice versa without having to disconnect the
15   filter media from the power supply.

          The filter element and seal leg combination 13 and
25 suspended within housing 3 is substantially
electrically isolated (i.e., isolated from ground) so
that when the power supply is energized during operation
20   of the apparatus, the filter media becomes
electrostatically charged. Thus, housing 3, outlet port
7 and fitting 11 are constructed of electrically
insulative materials and the entire filter element and
seal leg combination is sufficiently separated from
25   grounded, electrically conductive elements of the
apparatus to inhibit excessive spark over under design
operating conditions. Furthermore, all components of the
apparatus within the housing (e.g., upper support plate
18 and a lower support plate 19) should be substantially
30   free of protrusions, overhang and sharp edges which might
tend to undermine the electrical isolation of the filter
element and seal leg combination 13 and 25. Because

draining liquid exiting overflow pipe 31 and flowing as a
continuous stream to the bottom of housing 3 would
compromise the electrical isolation of the filter element
and seal leg combination by providing an electrical

5   connection to ground, care must be taken to maintain
sufficient discontinuity in this flow. This is achieved
in part by the distance separating the exit end of
overflow pipe 31 from the liquid level in the bottom of
housing 3. Also, the periphery of the exit end of the

10   overflow pipe may be serrated as shown in Fig. 1 so that
liquid passes from the overflow pipe at a multiplicity of
alternate drip points. The dimensions of the overflow
pipe and the geometry and linear density of the
serrations is preferably sufficient such that the liquid

15   drain rate per drip point is no more than about 0.38
l/min., more preferably, no more than about 0.19 l/min.
at the maximum design filter element irrigation rate. To
further inhibit the potential for draining liquid exiting
overflow pipe 31 from undermining the electrical

20   isolation of the filter element and seal leg combination,
the apparatus shown in Fig. 1 may further include one or
more high velocity nozzles 41 extending through the sides
of housing 3 at an elevation below the exit end of
overflow pipe 31. High velocity nozzles 41 are in

25   selective fluid communication with a pressurized source
(not shown) of gas (e.g., air) or liquid (e.g., water)
and are used to inject a high velocity spray of gas or
liquid into the housing that intersects and disrupts the
flow of liquid leaving the drip points about the

30   periphery of the exit end of overflow pipe 31. Because
extremely large volumes of gas may be required to create
the momentum required to sufficiently disrupt the flow of

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liquid exiting the overflow pipe, high pressure nozzles
41 are preferably supplied with a liquid such as water.
For example, two high pressure nozzles 41 which emit a
flat, 80° spray of water (e.g., 15 l/min. at 275

5   kilopascals (kPa) absolute) in a plane perpendicular to
the flow of liquid exiting overflow pipe 31 may be
disposed on opposite sides of housing 3. High pressure
nozzles 41 may be operated continuously or in
intermittent fashion coincident with increased filter

10   element irrigation when the liquid flow rate exiting
overflow pipe 31 is increased.

        To further ensure electrical isolation of the filter
element and seal leg combination 13 and 25, the apparatus
of the present invention preferably further includes

15   means for introducing a purge gas into defined spaces or
gaps separating the filter element and seal leg
combination from grounded elements of the apparatus so as
to inhibit excessive spark over which might otherwise
result due to electrically conductive material being

20   deposited on surfaces within the apparatus during
operation. In addition, by introducing purge gas into
these gaps, the size of the separation necessary to
sufficiently inhibit spark over at the desired maximum
design voltage may be reduced, along with the overall

25   dimensions of the apparatus.

        As shown in Fig. 1, a purge gas box 42 is joined to
the interior of the top side of housing 3 in coaxial
relationship with clean gas conduit 9. The purge gas box
is made of electrically insulative material and has an

30   annular lower portion 43 through which the clean gas
conduit extends. The lower portion of the purge gas box
is sized so that it is separated from the exterior of the

clean gas conduit by an annular gap 45. A purge gas
nozzle 47 extends through the top side of the housing
into purge gas box 42 and is in selective fluid
communication with a pressurized supply of clean, dry,

5   air or other purge gas (not shown). Preferably,
atmospheric air introduced as purge gas into the
apparatus of the present invention is first filtered to
remove contaminants and heated to raise its dew point
sufficiently to avoid condensation on surfaces within the

10 apparatus. Purge gas introduced into purge gas box 42
passes through annular gap 45 and exits the apparatus
through filter element 13. The flow of purge gas through
the annular gap inhibits electrically conductive material
entrained in the untreated gas (e.g., water droplets and

15 soluble and insoluble solids) from depositing on surfaces
within the purge gas box and the surfaces defining the
annular gap. Such coatings would tend to undermine the
electrical isolation of the filter element and seal leg
combination by providing an electrical connection to

20 ground. The volumetric flow rate of purge gas introduced
into purge gas box 42 should be selected relative to the
cross-sectional area of annular gap 45 so that purge gas
flows through the gap at a velocity adequate to prevent
deposition of electrically conductive material entrained

25 in the untreated gas sufficient to cause excessive spark
over under design operating conditions.

It should be understood that substantial electrical
isolation of the filter element and the high voltage
connection thereto may be suitably achieved using other

30 designs and techniques of the type used by those skilled
in the art of electrostatic precipitators. An example of
one such alternative design is shown in Fig. 2.

24

Fig. 2 is a fragmentary, longitudinal section of a
gas cleaning apparatus 1a in accordance with another
embodiment of the present invention with portions broken
away to show the internal construction thereof. The

5   direction of gas flow through the apparatus is indicated
by arrows in Fig. 2. Unless otherwise noted herein, gas
cleaning apparatus 1a shown in Fig. 2 is substantially
similar to apparatus 1 described above and shown in Fig.
1. The design shown in Fig. 2 is believed to be more

10 representative of an apparatus that can be adapted to
commercial application of the present invention.

In Fig. 2, filter element and seal leg combination
13 and 25 are suspended within housing 3 from clean gas
conduit 9a which in turn extends into and threadedly

15 engages or is otherwise secured to the bottom of a clean
gas box 51. Thus, clean gas exiting the filter element
flows through the clean gas conduit into the clean gas
box and is discharged through outlet port 7. A tubular
metal jacket 53 surrounds the clean gas conduit in

20 coaxial relationship therewith and supports clean gas box
51 above housing 3. The interior of jacket 53 is
separated from the exterior of clean gas conduit 9a by an
annular gap 45a. A ground electrode 37a is disposed
within clean gas box 51. Like ground electrode 37

25 disposed within housing 3, ground electrode 37a is
comprised of electrically conductive material and, as
shown in Fig. 2, may comprise a metal screen fixed
adjacent to the interior surface of the lateral sides of
the clean gas box.

30 An electrical connection between one terminal of
direct current power supply 39 and the electrically
conductive filter media 15 is provided through liquid

25

drain conduit 27 of seal leg 25 via a high voltage feed
through design of the type conventionally employed in
electrostatic precipitators. As shown in Fig. 2, this
includes a conduit 55 made of electrically insulative

5   material and extending into housing 3 adjacent the seal
leg. The high voltage lead from power supply 39 passes
through conduit 55 and is connected to liquid drain
conduit 27. Liquid drain conduit 27 and lower support
plate 19 are made of electrically conductive material

10   (e.g., stainless steel) such that these components of the
apparatus are electrically connected to filter media 15.
Ground electrodes 37 and 37a and jacket 53 are connected
to the grounded terminal (positive or negative) of power
supply 39. As shown in Fig. 2, the electrical connection

15   between the grounded terminal of the power supply and
ground electrode 37a is provided by one or more
electrically conductive lugs 40a extending through the
lateral side of clean gas box 51 and contacting the
ground electrode. Similarly, jacket 53 is connected to

20   the grounded terminal of the power supply by an
electrically conductive lug 40b.

The filter element and seal leg combination 13 and
25 suspended within housing 3 is substantially
electrically isolated from ground so that when the power

25   supply is energized during operation of the apparatus,
the filter media becomes electrostatically charged.
Thus, in this embodiment, housing 3, clean gas conduit 9a
and clean gas box 51 are constructed of electrically
insulative materials and the entire filter element and

30   seal leg combination is sufficiently separated from
grounded, electrically conductive elements of the
apparatus to inhibit excessive spark over under design

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operating conditions as described above. In addition,
purge gas nozzles 47a in selective fluid communication
with a pressurized supply of filtered, heated air or
other purge gas (not shown) extend through jacket 53 and
5   are directed into gap 45a. Multiple purge gas nozzles
47a at the same elevation may be positioned at 90°
increments about jacket 53. Purge gas introduced into
gap 45a inhibits electrically conductive material
entrained in the untreated gas from depositing on the
10   interior surface of jacket 53 and the exterior surface of
clean gas conduit 9a which might otherwise cause spark
over between these two components at an applied voltage
lower than the desired maximum design voltage. The
volumetric flow rate of purge gas introduced into jacket
15   53 should be selected relative to the cross-sectional
area of annular gap 45a so that purge gas flows through
the gap at a velocity adequate to prevent deposition of
electrically conductive material entrained in the
untreated gas sufficient to cause excessive spark over
20   under design operating conditions. The velocity of the
purge gas through annular gap 45a necessary to avoid
excessive spark over will generally decrease as the size
of the gap increases and also depends on other factors as
well such as the composition of the purge gas.
25   Typically, the velocity of purge gas through annular gap
45a should be at least about 0.05 m/s.

      There is also a purge gas annulus 48 positioned
adjacent the bottom interior surface of clean gas box 51.
The purge gas annulus is of hollow tubular construction
30   and is also in selective fluid communication with a
pressurized supply of purge gas (not shown) via couplings
49. The purge gas annulus has a multiplicity of holes

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48a spaced about its internal diameter. Purge gas
introduced into purge gas annulus 48 flows out through
the multiplicity of holes 48a and over the interior
surface of the bottom of clean gas box 51 and the
5   surfaces of clean gas conduit 9a extending into the clean
gas box to inhibit electrically conductive material
entrained in the treated gas from depositing on these
surfaces. Likewise, the volumetric flow rate of purge
gas introduced into annulus 48 should be selected
10   relative to the total gas flow area provided by holes 48a
so that purge gas flows through the holes at a velocity
adequate to prevent deposition of electrically conductive
material entrained in the untreated gas sufficient to
cause excessive spark over under design operating
15   conditions. Conduit 55 is provided with a purge gas port
57 through which filtered, heated air or other purge gas
is introduced from a pressurized source (not shown) into
conduit 55. In a similar fashion, purge gas is
introduced into conduit 55 at a rate sufficient to
20   prevent excessive spark over from the high voltage lead
connected to liquid drain conduit 27 as it enters housing
3.

        The process in accordance with the present invention
is now described in detail with reference to the
25   apparatus 1 and 1a shown in Figs. 1 and 2, respectively.

        Fogging nozzles 23 are activated to introduce an
aqueous liquid into housing 3 in the form of a dense fog
and the flow of purge gas from purge gas nozzles 47 and
47a through annular gaps 45 and 45a is started. In
30   apparatus 1a shown in Fig. 2, the flow of purge gas from
annulus 48 into clean gas box 51 and through purge gas
port 57 into conduit 55 is also initiated. Power supply

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39 is energized such that a high voltage electric
potential (positive or negative) is applied to filter
media 15 of the substantially electrically isolated
filter element 13. This results in the filter media

5   becoming electrostatically charged. A limited direct
current discharge between the electrostatically charged
filter element 15 and ground electrode 37 imposes an
electric field between these two elements of the
apparatus.

10   The gas to be treated is introduced into housing 3
through inlet port 5 and is contacted by the aqueous fog
injected into the housing by the fogging nozzles. Liquid
droplets and solid particles entrained in the wetted gas
pass through the imposed electric field as the gas drag

15   forces drive the particles toward filter element 13. The
electric field induces a charge on the entrained
particles of opposite polarity with respect to the charge
on filter media 15. As the gas enters the filter element
and flows through the electrostatically charged filter

20   media, the charged particles are separated from the gas
stream by conventional gas filtration mechanisms (e.g.,
sieving, impaction, interception, and diffusion) in
addition to being electrostatically attracted to the
surface of the oppositely charged filter media. This

25   electrostatic attraction contributes significantly to the
collection of all particles regardless of size, but is
especially beneficial in the capture of submicron
particles which may tend to evade separation by
conventional filtration mechanisms.

30   Captured liquid droplets wet filter media 15 with an
aqueous liquid film. The captured liquid continuously
drains through the structure of the wetted filter media

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under the force of gravity. Gas drag forces exerted by
the gas as it passes through filter element 13 impart a
horizontal component of movement to the draining liquid
toward the downstream surface of the filter media. As

5   the liquid drains through the filter media, it removes
captured solid particles and produces a liquid waste
stream containing the removed particles which collects on
lower support plate 19 and exits the filter element
through the seal leg 25 before eventually being

10 discharged from the apparatus through liquid drain port
35. The liquid waste may be recirculated and introduced
again into housing 3 through fogging nozzles 23. In
order to control the solids content of the recirculating
water, appropriate purge and clean make-up water streams

15 may be employed. Preferably, the solids content of the
recirculating water is maintained no higher than about 5
g/l, more preferably no higher than about 1 g/l.

Clean gas, substantially free of entrained particles
flows from the interior of the filter element through

20 clean gas conduit 9 and 9a and exits housing 3 through
outlet port 7. It has been observed that any particles
remaining in the cleaned gas stream exiting the apparatus
in accordance with the present invention are extremely
highly charged, having a polarity which is the same as

25 that of the electrostatic charge on filter element 13.
The mechanism behind this charging effect is not fully
understood.

Depending on the design criteria, the magnitude of
the electric potential applied to filter media 15 may

30 vary considerably. Generally, the higher the electric
potential applied to the filter media the greater the
improvement in particle collection efficiency realized.

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In order to maximize the beneficial effects of
electrostatic attraction on the particle collection
efficiency, power supply 39 preferably remains energized
throughout the gas cleaning process such that an electric
5   potential is applied to the filter media continuously.
Preferably, the applied voltage is substantially
maintained at a magnitude just below that which would
result in spark over between the substantially
electrically isolated filter element and seal leg
10   combination 13 and 25 and the grounded elements of the
apparatus at the prevailing operating conditions within
the apparatus.   This preferred mode of operation is
readily achieved using automatic voltage control means of
the type conventionally employed in power supplies
15   associated with electrostatic precipitators. The
operating range for the applied voltage controlled in
this fashion will vary from application to application
depending on a variety of factors such as the size and
geometry of the filter element, materials of
20   construction, the composition of the gas within the
housing, the distance separating the filter element and
seal leg combination from grounded elements of the
apparatus as well as other factors contributing to the
electrical isolation of the filter element and seal leg
25   combination. In some applications, the electric
potential applied to the filter media may be maintained
no higher than about 0.5 kilovolt (kv) and suitable
results achieved. However, in most applications, it will
be preferred to construct and operate the apparatus in
30   accordance with the present invention such that the
electric potential applied to the filter media is
maintained at a much higher magnitude. Typically, the

magnitude of the electric potential applied to the filter
media will be at least about 10 kv, preferably from at
least about 10 kv to about 70 kv, more preferably from at
least about 20 kv to about 50 kv. The average voltage

5   gradient at the upstream surface of the filter media will
typically range from about 0.8 kv/cm to about 8.0 kv/cm,
more preferably from about 2.0 kv/cm to about 4.0 kv/cm.
Although an electric potential is preferably applied to
the filter media throughout the gas cleaning process, it

10   is also possible to apply the electric potential
intermittently.

As noted above a limited direct current discharge
between the electrostatically charged filter element and
the ground electrode imposes an electric field between

15   these two elements of the apparatus. However, it should
be understood that compared to conventional wet
electrostatic precipitators, the operating current of the
present apparatus is extremely low. That is, due to the
substantial radius of curvature of the filter element 13,

20   it functions as an essentially non-emitting surface.
Typically, the current density per unit of gas flow area
of the filter element will be no greater than about 10
mA/m^2, more preferably no greater than about 2 mA/m^2. It
is believed that in larger scale units (e.g., having a

25   gas flow capacity of about 60 m^3/min. or more) in
accordance with the present invention, high particle
collection efficiencies and low pressure drops can be
maintained with average electrical power requirements
associated with electrostatically charging the filter

30   element typically ranging from about 20 watts to about
500 watts.

Fogging nozzles 23 may be operated continuously throughout the gas cleaning process or intermittently. The filter element irrigation rate necessary for satisfactory operation of the apparatus will vary from one application

5   to another and can be readily determined. Typically, build-up of collected insoluble material within electrically conductive filter media 15 can be sufficiently inhibited and a steady state pressure drop across filter element 13 achieved by operating the fogging

10 nozzles so that the average filter element irrigation rate per unit of gas flow area is from about 0.40 l/min./m² to about 4.0 l/min./m². In accordance with a preferred mode, the fogging nozzles are operated such that during large portions of the process, the filter element is irrigated

15 at a rate less than the minimum necessary to prevent build-up of collected insoluble material in the electrically conductive filter media. Then, at intervals depending on the extent to which the filter media has become clogged, as indicated by an increase in pressure

20 drop across the filter element, the rate at which the filter element is irrigated is increased for a relatively short period of time to flush collected solid particles and regenerate the filter media. The flow of liquid introduced into the housing by the fogging nozzles may be

25 reduced during periods of low filter element irrigation or the nozzles may be turned completely off. Operating the fogging nozzles in this manner conserves the energy necessary to pump the liquid supplied to the fogging nozzles and may also allow the operating voltage applied

30 to filter element 13 to be maintained at a higher value during periods of low filter irrigation due to the decreased conductivity of the gas within the housing.

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In accordance with a preferred embodiment of the present invention, the polarity of the electrostatic charge on the filter media is selected to enhance the removal of captured solid particles from the wetted filter

5   media.

In the practice of the present invention, insoluble solid particles captured in the filter media are more or less dispersed in the liquid wetting and draining from filter media 15. When an insoluble solid particle is

10   contacted with a liquid medium, as in this suspension of captured particles, an electric double layer is formed at the solid-liquid interface comprising an array of either positive or negative electric charges attached to or adsorbed on the surface of the particle and a diffuse

15   layer of charges of opposite sign surrounding the charged surface of the particle and extending into the liquid phase. The electrokinetic potential across the double layer is known as the zeta potential. Although the polarity of the zeta potential may change from one

20   captured particle to another within the suspension, the polarity of the zeta potential for the suspension as a whole is characterized by the polarity of the surface charge attached to a predominant number of captured solid particles within the suspension. That is, a majority of

25   the insoluble particles in the suspension will have either a positive or negative surface charge.

Both the magnitude and polarity of the zeta potential for the suspension of solid particles captured in the filter media will vary from application to application

30   depending on the composition of the captured particles and the liquid wetting the filter media, as well as other factors, including the particle size distribution and the

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temperature and pH of the suspension. Aqueous suspensions
of metallic hydroxides and hydrated oxides and basic
dyestuffs tend to exhibit positive zeta potentials (i.e.,
a positive surface charge is attached to the solid

5   particles), while aqueous suspensions of metals, sulfur
compounds, acidic hydroxides and acidic dyestuffs tend to
exhibit a negative zeta potential (i.e., a negative
surface charge is attached to the solid particles). The
magnitude and polarity of the zeta potential for a

10   suspension of solid particles in a liquid medium is
calculated from the electrophoretic mobilities (i.e., the
rates at which solid particles travel between charged
electrodes placed in the suspension) and can be readily
determined using commercially available

15   microelectrophoresis apparatus.

In the practice of the preferred embodiment, the
polarity of the electric potential applied to filter media
15 is selected such that the electrically conductive
material has a charge of the same polarity as the charge

20   attached to the surface of a predominant number of solid
particles captured in the wetted filter media. Thus, the
charge on the electrically conductive material preferably
has the same polarity as the zeta potential for the
suspension of captured solid particles draining from the

25   filter media. During operation, this results in a
predominant number of captured solid particles being
repulsed from the surface of the filter media by
electrophoresis and advantageously allows the liquid phase
of the suspension draining through the structure of the

30   filter media to more easily remove these insoluble
particles from the filter media.

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In this preferred embodiment, the polarity of the electric potential to be applied to the filter media may be determined by preparing and determining the zeta potential of a solid-liquid mixture representative of the

5   suspension of insoluble particles that will be present in the wetted filter media at the prevailing operating conditions. That is, the electric potential applied to the filter media is selected such that the charge on the electrically conductive material has the same polarity as

10   the surface charge attached to a predominant number of the solid particles within the representative system.

In some applications, it may be advantageous to periodically switch the polarity of the electric potential applied to filter media 15 such that the charge on the

15   electrically conductive material alternates between positive and negative. That is, the control means of direct current power supply 39 is used to switch the function of the filter media 15 and ground electrode 37 from cathode and anode to anode and cathode, respectively,

20   and *vice versa*. Periodically switching the polarity of the electric potential applied to the filter media will cause both solid particles having a positive surface charge and solid particles having a negative surface charge to be alternately repulsed from the wetted filter

25   media and thereby enhance the overall removal of captured solid particles from the filter media by the draining liquid phase. Alternating the polarity of the electric potential applied to the filter media may be especially advantageous in applications where the suspension of

30   captured solid particles in the filter media contains a high proportion (e.g., from about 30 percent to about 70 percent) of both solid particles having a positive surface

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charge and solid particles having a negative surface
charge. In such applications, the period during which the
charge on the filter media is of a selected polarity,
either positive or negative, is preferably proportional to
5   the fraction of captured solid particles in the suspension
having a charge of the same polarity attached to the
surface of the particle. For example, if 60 percent of
the captured solid particles in the suspension have a
positive surface charge and the remainder have a negative
10   surface charge, the period during which the filter media
is positively charged is preferably about 50 percent
longer than the period during which the filter media is
negatively charged.

Although a preferred embodiment has been described in
15   which the polarity of the charge on the filter media is
selected to have the same polarity as the zeta potential
of the suspension of captured solid particles draining
from the filter media, it should be understood that
satisfactory results may be achieved by the present
20   invention even in the absence of this preferred mode of
operation. However, in those applications where the
preferred mode of operation is not employed (i.e., the
polarity of the charge applied to the filter media is
opposite of the polarity of the zeta potential for the
25   suspension of captured solid particles), it may be
necessary to increase the rate at which the filter element
is irrigated to adequately flush collected insoluble
material and regenerate the filter media.

Fig. 3 is a longitudinal section of a gas cleaning
30   apparatus 1b in accordance with a further alternative
embodiment of the present invention. This design is
believed to be especially representative of a commercial

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adaptation of the apparatus of the present invention. The
operation and various components of this further
embodiment are substantially similar to that already
described with respect to the apparatus 1 and 1a shown in
5   Figs. 1 and 2, respectively. Accordingly, the significant
differences are emphasized in the following description,
it being understood that apparatus 1b, the function of its
components and operation thereof are otherwise in accord
with the preceding description.

10   In Fig. 3, housing 3a comprises a vertical cylinder
of circular cross-section open at top and bottom flanged
ends 3b and 3c, respectively. The filter element and seal
leg combination 13 and 25 are suspended within housing 3a
from clean gas conduit 9b. Clean gas conduit 9b has an
15   upper flange 9c and a lower flange 9d and is suitably made
of electrically insulative, corrosion-resistant material
such as FRP. Upper flange 9c is fixed at its periphery to
the interior surface of housing 3a and lower flange 9d is
joined to filter element 13. The clean gas conduit,
20   filter element and seal leg assembly 9b, 13 and 25 is in
coaxial relationship with cylindrical housing 3a such that
an annular gap 45b separates the interior surface of the
housing from the exterior surface of the clean gas conduit
both above and below upper flange 9c. The bottom end 3c
25   of housing 3a serves as an inlet for introducing the gas
to be treated into the housing. Gas introduced into the
housing flows upwardly and through filter element 13.
Clean gas exiting the filter element flows through clean
gas conduit 9b before being discharged from top end 3b of
30   the housing which serves as a clean gas outlet. The
bottom end 3c of housing 3a also serves as a liquid drain

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port through which liquid waste draining from seal leg 25 is removed from the housing.

In the embodiment shown in Fig. 3, the ground electrode 37b is made integral with the housing. More

5   specifically, the interior surface of housing 3a is made of a sufficiently electrically conductive, corrosion-resistant material and serves as the ground electrode. For example, ground electrode 37b may be made integral with housing 3a by constructing the housing from an

10   electrically insulative, corrosion-resistant material such as FRP and lining its interior surface with a layer of static dissipative plastic. A ground electrode comprising a static dissipative plastic coating may be formed by lining the interior of the housing with a carbon fiber or

15   graphite veil and depositing thereon a plastic resin having a high (e.g., 10-30% by weight) particulate metal (e.g., graphite) content. The resistivity of the interior surface of housing 3a which serves as ground electrode 37b should be no more than about 1×10^4 ohm·cm, more

20   preferably no more than about 1×10^3 ohm·cm. Static dissipative plastic coatings on FRP of the type used in the practice of the present invention are well-known in the field of electrostatic precipitators and can be manufactured by Cortol Process Systems, Inc., Hazelwood,

25   Missouri, U.S.A.

An electrical connection between one terminal of direct current power supply 39 and filter element 13 is provided through seal leg 25 via a high voltage feed through design similar to that shown in Fig. 2. As shown

30   in Fig. 3, this includes a flanged conduit 55a which extends into housing 3a adjacent seal leg 25. Conduit 55a is joined at its flanged end to a high voltage feed pipe

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56 provided with a purge gas port 57a through which clean,
dry, air or other purge gas from a pressurized source (not
shown) is introduced. The end of the high voltage feed
pipe 56 opposite conduit 55a terminates at high voltage
5   power supply 39. The conduit 55a and high voltage feed
pipe 56 assembly is referred to as the high voltage bus
duct 58. The high voltage lead from power supply 39 is
fed into high voltage bus duct 58 and connected to a rod
59. Rod 59 is fixed within high voltage bus duct 58 by
10   threadedly engaging and passing through a feed through
ceramic insulator 61 having a mounting flange 63 joined at
its periphery to the interior of high voltage feed pipe
56. Mounting flange 63 is provided with holes to allow
purge gas introduced through purge gas port 57a to flow
15   through high voltage bus duct 58 and into housing 3a. Rod
59 extends along the centerline of high voltage bus duct
58 into housing 3a. A seal leg connector pipe 65 extends
from the bottom side of seal leg cup 29 and is joined to
rod 59 by T-connector 67. Rod 59, seal leg connector pipe
20   65, T-connector 67, seal leg 25 and lower support plate 19
are all made of electrically conductive material (e.g.,
stainless steel) such that one terminal of power supply 39
is electrically connected to filter element 13.

     The construction of seal leg 25 and the manner in
25   which seal leg connector pipe 65 is joined to the bottom
side of seal leg cup 29 is shown in greater detail in Fig.
4. Fig. 4 is an enlarged section taken in the plane
including line 4--4 in Fig. 3. The seal leg comprises
liquid drain conduit 27 extending into seal leg cup 29.
30   The seal leg cup is of circular cross-section and is
secured to the liquid drain conduit by several tabs 29a
which extend from the sides of the seal leg cup. Tabs 29a

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are relatively small such that the seal leg cup is substantially open across the top. A scalloped edge 29b extends downwardly from the periphery of the bottom side of seal leg cup 29. Only a portion of scalloped edge 29b

5 is shown in Fig. 4, it being understood that the scalloped edge extends around the entire periphery of the bottom side of seal leg cup 29. Liquid waste draining from filter element 13 passes through liquid drain conduit 27 and into seal leg cup 29. Liquid waste overflows through

10 the top of seal leg cup 29 and flows down the sides to a multiplicity of alternate drip points provided by scalloped edge 29b.

Seal leg connector pipe 65 has a flanged end 65a fixed to the end thereof opposite T-connector 67. Flanged

15 end 65a abuts the bottom side of seal leg cup 29 and is held in place by retention plate 68 which in turn is fixed to the bottom side of the seal leg cup by threaded studs 69. The construction shown in Fig. 4 allows selective orientation of the seal leg connector pipe and T-connector

20 combination 65 and 67 such that it can be readily aligned with rod 59 extending into housing 3a from high voltage bus duct 58.

Conduit 55a and high voltage feed pipe 56 shown in Fig. 3 may suitably be made from electrically insulative,

25 corrosion-resistant material such as FRP. In addition, ground electrode 37b extends into and is made integral with high voltage bust duct 58 by lining the interior surface of conduit 55a and high voltage feed pipe 56 with a sufficiently electrically conductive and corrosion-

30 resistant material as described above with respect to housing 3a. The grounded terminal of power supply 39 is electrically connected to ground electrode 37b integrated

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in housing 3a and high voltage bus duct 58 by one or more
grounding lugs 40c extending into these components into
contact with the ground electrode. Although only two are
shown in Fig. 3, a multiplicity of grounding lugs 40c are
5   preferably uniformly distributed over substantially the
entire housing 3a and high voltage bus duct 58 with an
areal density of at least about 10 lugs/m^2.
Alternatively, housing 3a, conduit 55a and high voltage
feed pipe 56 may be constructed from carbon steel and
10 lined with a static dissipative plastic coating or other
sufficiently electrically conductive, corrosion-resistant
material to form an integral ground electrode 37b. This
may provide cost advantages over FRP and other materials
of construction and would allow the connection between the
15 ground electrode and the grounded terminal of the power
supply to be made from the external surfaces of the
apparatus.

As shown in Fig. 3, housing 3a is further provided
with purge gas nozzles 47b both above and below upper
20 flange 9c through which heated, filtered air or other
purge gas from a pressurized source (not shown) is
introduced into gap 45b. Purge gas introduced into gap
45b inhibits electrically conductive material entrained in
the untreated gas from depositing on the interior surface
25 of housing 3a and the exterior surface of clean gas
conduit 9b which might otherwise undermine the substantial
electrical isolation of the filter element and seal leg
combination 13 and 25 at the desired maximum design
voltage.

30   Fogging nozzles 23 for irrigating the filter element
13 are threaded into the sides of housing 3a and terminate
flush with the interior surface of the housing. The

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fogging nozzles may be made of metal or plastic and are in selective fluid communication with a source of liquid (not shown). The fogging nozzles in Fig. 3 are positioned at several elevations adjacent filter element 13. One or

5   more sets of fogging nozzles 23, each set containing multiple nozzles positioned at the same elevation around housing 3a (e.g., sets of four fogging nozzles at 90° increments) may be employed. If sets of multiple fogging nozzles 23 positioned around the housing at various

10 elevations are employed, it may be advantageous to increase the flow rate of liquid through each set of nozzles at different times. For example, once the pressure drop across the filter element has increased to a predetermined value during the gas cleaning process, the

15 flow rate of liquid through the set of nozzles at the highest elevation may be increased first followed by each set at lower elevations in succession from top to bottom. Of course, operation of the fogging nozzles in any desired manner is readily adapted to automated control.

20   The apparatus 1b shown in Fig. 3 can be designed to handle a gas flow capacity of 60 m³/min. or more. However, there are practical limitations to the size of gas cleaning apparatus in accordance with the present invention. For applications requiring even larger gas

25 flow rates, multiple gas cleaning apparatus can be operated in parallel. The embodiment shown in Fig. 3 is readily adapted to a modular system configuration wherein varying numbers of gas cleaning apparatus (i.e., modules) may be operated in parallel to provide a gas cleaning

30 system of any desired gas flow capacity. An example of a modular gas cleaning system 70 in accordance with the present invention is shown in Fig. 5.

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Fig. 5 is an elevation and partial schematic of a modular gas cleaning system in accordance with the present invention with portions broken away to show the internal construction thereof. The system shown in Fig. 5 includes
5   a first gas cleaning apparatus or module 71 identical to the apparatus 1b shown in Fig. 3. The system further includes an intake manifold 73 and a clean gas manifold 75 provided with flanged ports 77 sized for connection to bottom flanged end 3c and top flanged end 3b of module 71.
10 The intake and clean gas manifolds further include one or more pairs of additional flanged ports 79. Thus, the intake and clean gas manifolds are adapted for connection to a variable number of modules such that the system may accommodate variations in gas flow capacity demands as
15 needed. A second such module 81 is shown in phantom in Fig. 5 having its bottom flanged end 3c and top flanged end 3b connected to flanged ports 79 of the intake and clean gas manifolds, respectively. The second module is also identical to the gas cleaning apparatus 1b shown in
20 Fig. 3, except that it is not provided with a high voltage feed as previously described. Accordingly, conduit 55a of module 81 is closed at its flanged end. The electrical connection between modules 71 and 81 and power supply 39 is described in detail below. Once the system is
25 assembled, the intake and clean gas manifolds are in fluid communication through the modules. If a second module is not required, flanged ports 79 are simply closed with a blind flange.

Intake and clean gas manifolds 73 and 75 may be
30 suitably constructed of FRP or other electrically insulative, corrosion-resistant material. Furthermore, ground electrode 37b may extend into and be made integral

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with the interior surface of the intake and clean gas
manifolds by lining these components with a static
dissipative plastic coating or other sufficiently
electrically conductive, corrosion-resistant material as
5   described above with respect to housing 3a of modules 71
and 81. The grounded terminal of power supply 39 is
electrically connected to ground electrode 37b integrated
in intake and clean ·gas manifolds 73 and 75 by one or more
grounding lugs 40c extending into these components into
10   contact with the ground electrode.

        Intake manifold 73 is provided with a gas inlet duct
83 through which gas to be treated is introduced into the
system. One or more fogging nozzles 23 are directed into
gas inlet duct 83 such that gas to be treated upon
15   entering the system is contacted with a liquid spray and
liquid droplets from the fogging nozzles are entrained in
the gas to be treated. Preferably, the incoming gas is
substantially saturated with liquid. The intake manifold
distributes the flow of gas to be treated between modules
20   71 and 81. The intake manifold also serves as a universal
sump for collecting liquid waste draining from modules 71
and 81 during the gas cleaning operation. Liquid waste is
removed from the intake manifold through sump drain 84.
The gas to be treated passes from intake manifold 73
25   upwardly through modules 71 and 81 and clean gas is
collected in clean gas manifold 75. A fan or blower 85
connected to a clean gas exit port 87 on clean gas
manifold 75 provides the motive force for moving gas
through the system.

30   The filter media within element 13 of modules 71 and
81 may be electrostatically charged by a single high
voltage direct current power supply 39. The electrical

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connection between module 71 and one terminal of the power
supply is provided by the high voltage feed through
connection shown in Fig. 3 and described above. The
filter media within filter element 13 of module 81 is in
5   turn connected to power supply 39 in parallel to the
filter media within filter element 13 of module 71. As
shown in Fig. 5, the electrical connection between the
filter media in modules module 71 and 81 may pass through
the intake manifold. This connection is readily provided
10   by a module connector rod 89 extending from the T-
connector 67 beneath seal leg 25 in module 71 through
intake manifold 73 above the liquid level line and joining
T-connector 67 beneath seal leg 25 in module 81.
Conventional pipe connectors 91 may be used in routing
15   module connector rod 89 from one module to another. Both
the module connector rod and the associated pipe
connectors are made of electrically conductive material
(e.g., stainless steel).

A modular gas cleaning system in accordance with the
20   present invention may employ multiple direct current power
supplies to separately charge the filter element of each
module. For example, each module could be provided with a
separate high voltage feed through connection of the type
shown in Fig. 3. Such an arrangement may improve the
25   degree of control possible with respect to minimizing
spark over within each individual module under design
operating conditions. However, it is believed that the
benefits of such an approach will be outweighed in most
applications by the increased system complexity and higher
30   capital and operating expenditures.

Although the system shown in Fig. 5 includes only two
modules, the modular system in accordance with the present

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invention can be constructed so as to readily accommodate
any number of modules to provide a system that can adapt
to wide ranging gas flow capacity demands, for example, in
the case of plant expansion. Other advantages of the

5   modular gas cleaning system include flexible layout and
space requirements, ease in delivering additional modules
ready for installation at a plant site and improved
safety.

Various modifications and adaptations of the process

10   and apparatus disclosed above are possible. For example,
the filter element containing the electrically conductive
filter media need not be in the form of a substantially
vertical cylinder but might instead be in the form of a
bag, pleated element, flat or any other suitable shape.

15   It may be desirable to operate two or more gas cleaning
apparatus of the present invention in series such that
treated gas exiting a first apparatus is fed to a second
apparatus. Such an arrangement might be useful in
applications requiring extremely high particle collection

20   efficiencies. Furthermore, a gas cleaning system having
high gas flow capacity may be provided by suspending
multiple filter elements in accordance with the present
invention from a flange within a single vessel provided
with appropriate grounding elements, high voltage, purge

25   air and liquid spray feeds. However, due to the increased
complexity and higher capital costs, such an alternative
gas cleaning system is believed to be less preferred than
the modular system described above.

The present invention is illustrated by the following

30   examples which are merely for the purpose of illustration
and are not to be regarded as limiting the scope of the
invention or manner in which it may be practiced.

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EXAMPLE 1

In the following examples, gas cleaning apparatus in accordance with the present invention were operated to remove fine bentonite clay particles (Fisher Scientific, Fairlawn, New Jersey, U.S.A., Catalog No. B 235-500) entrained in air streams. Tap water was used to humidify the gas to be treated and irrigate the filter element.

The experimental system included a gas inlet conduit connected to the inlet port of the gas cleaning apparatus for introducing a gas stream to be treated into the housing of the apparatus and a gas outlet conduit connected to the outlet port of the apparatus through which clean gas was discharged from the housing of the apparatus. A gas blower (EG & G, Saugerties, New York, U.S.A., Model Rotron DR 505, 4.5 Nm^3/min. max., 20.7 kPa) connected to the gas outlet conduit was used to draw the gas to be treated through the gas cleaning apparatus. Gas sampling ports provided in the gas inlet and outlet conduits were used to direct samples of gas flowing through the conduits to conventional inertial impactors (Anderson, Smyrna, Georgia, U.S.A., Model Mk3) to determine particle concentrations in the gas streams and fractional collection performance of the gas cleaning apparatus as described in greater detail below.

The gas inlet conduit further included a dust feed port upstream of the gas sampling port. A screw-type dust feeder was connected to the dust feed port for feeding bentonite clay particles into the inlet conduit. The gas to be treated was prepared by introducing bentonite clay particles fed by the dust feeder into a stream of ambient air drawn into the gas inlet conduit. The loading of bentonite clay particles in the gas to be treated was

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controlled by adjusting the speed of the motor used to drive the screw feeder. A high pressure air nozzle directed into the dust feed port was used to improve the dispersion of bentonite clay particles in the gas to be

5   treated.

Pressure taps and pressure gages were provided at appropriate locations in the gas cleaning apparatus to determine pressure drop across the filter element. Also, an electronic pressure differential cell was used to

10   continuously monitor the pressure drop across the filter element versus time. The gas flow rate through the gas cleaning apparatus was determined by the pressure drop across a calibrated orifice meter (North American, Cleveland, Ohio, U.S.A., orifice plate No. 2000) installed

15   in the gas outlet conduit.

The experimental setup further included a liquid waste recirculation pump and level controlling circuits designed such that experiments could be run either in a mode in which humidification and irrigation water passes

20   through the system a single time or in a mode in which liquid waste removed from the housing of the gas cleaning apparatus is recirculated through the fogging nozzles, with appropriate purge and make up water, to simulate field conditions. The recirculated liquid waste could be

25   used for both inlet gas humidification and irrigation of the filter element.

This Example demonstrates, among other things, the use of stainless steel wool as the electrically conductive filter media in the wet electrostatic filtration system of

30   the present invention. The filter element was constructed by winding approximately 2.2 kg of stainless steel wool comprised of fibers having a mean fiber diameter of about

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82 μm onto a cylindrical, perforated support screen having
an outside diameter of about 8.9 cm and a height of about
30.5 cm. The resulting layer of electrically conductive
filter media was substantially uniform having a thickness

5   of approximately 4.3 cm and a bulk density of about 415.2
kg/m³. The void fraction calculated for the layer of
stainless steel wool was 0.944. The pressure drop across
the dry stainless steel wool filter element was very low
(less than 0.01 kPa at a gas velocity of 15.2 cm/s). The

10 filter element was installed in the housing of a gas
cleaning apparatus substantially similar to the apparatus
shown and described in Fig. 1 such that the distance
separating the upstream surface of the layer of stainless
steel wool and the ground screen was about 5.9 cm.

15   Suspensions of bentonite clay particles in tap water
exhibit a negative zeta potential (i.e., have a negative
surface charge). Thus, in accordance with the preferred
embodiment of the present invention, the filter element
was electrically connected to the negative terminal of the

20 direct current power supply (SIMCO, Hatfield,
Pennsylvania, U.S.A., Model No. CH25) such that a negative
potential could be applied to the stainless steel wool
filter media.

        In all the tests conducted in this Example, the

25 system was operated such that the gas velocity through the
stainless steel wool filter media was about 18.8 cm/s and
the loading of bentonite clay particles and water droplets
in the gas introduced into the filter element was about
110 mg/m³ and about 53 g/m³, respectively. The fogging

30 nozzles were operated continuously to obtain a filter
element irrigation rate of about 0.61 1/min./m². The
filter element irrigation rate was determined by measuring

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the rate at which liquid waste drained directly from the
filter element. Furthermore, in this Example, the
experimental system was run in the once through water
mode. That is, fresh tap water was introduced through the
5   fogging nozzles for gas humidification and fiber bed
irrigation rather than supplying the fogging nozzles with
liquid waste recirculated from the housing of the gas
cleaning apparatus.

The only process variable which was changed in the
10   tests conducted in this Example was the magnitude of the
negative direct current voltage applied to the stainless
steel wool filter media. In three separate tests, the
voltage applied to the stainless steel wool filter media
was -20 kv (Test 1), -10 kv (Test 2) and 0 kv (Test 3).
15   During Tests 1 and 2 the current drawn by the direct
current power supply was about 0.8 mA and about 0.4 mA,
respectively.

During each of the three tests, samples of the gas to
be treated and of the clean gas were drawn from the
20   appropriate gas sampling port and directed to the
associated inertial impactor. Conventional isokinetic
sampling procedures were followed to eliminate sampling
errors. The solid and liquid material collected on the
several stage plates in the inertial impactors was dried
25   in a desiccator to remove moisture and then weighed. A
five place analytical balance (Mettler, Hightstown, New
Jersey, U.S.A., Model AT 261) was used for gravimetric
analysis. The concentration of bentonite clay particles
of various diameters in the gas to be treated and the
30   clean gas was then determined by dividing the dried weight
of material collected on an individual stage plate by the

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gas sample volume. The results are summarized below in Table 1.

TABLE 1

Particle Diameter (μm)	Inlet Conc. (mg/m³)	Test 1 -20 kv		Test 2 -10 kv		Test 3 0 kv	
		Exit Conc. (mg/m³)	Collection Efficiency (%)	Exit Conc. (mg/m³)	Collection Efficiency (%)	Exit Conc. (mg/m³)	Collection Efficiency (%)
≥ 7.22	98.746	0.004	100.00	0.509	99.46	0.219	99.78
< 7.22 ≥ 4.57	1.437	0.000	100.00	0.000	100.00	0.000	100.00
< 4.57 ≥ 3.03	0.656	0.009	98.70	0.006	99.09	0.000	100.00
< 3.03 ≥ 2.13	0.897	0.000	100.00	0.000	100.00	0.000	100.00
< 2.13 ≥ 1.35	2.815	0.000	100.00	0.005	99.82	0.002	99.94
< 1.35 ≥ 0.69	3.270	0.000	100.00	0.013	99.57	0.074	97.75
< 0.69 ≥ 0.40	1.611	0.002	99.88	0.053	96.60	0.023	98.55
< 0.40 ≥ 0.26	0.232	0.004	98.36	0.000	100.00	0.010	95.67
< 0.26	0.134	0.000	100.00	0.022	82.90	0.052	61.25
Total	109.797	0.018	99.98	0.607	99.42	0.380	99.65

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With the application of high direct current voltage
to the stainless steel wool filter media in Tests 1 and 2,
a very high collection efficiency was maintained, even for
submicron solid particles. Furthermore, in Tests 1 and 2,
5   the pressure drop across the wetted stainless steel wool
filter element remained essentially constant at about 0.07
kPa, indicating that collected bentonite clay particles
were being efficiently removed from the stainless steel
wool fibers by the draining liquid without a net decrease
10   in the operating void fraction of the filter media.
However, during the power off experiment in Test 3, the
collection efficiency of submicron solid particles
decreased, especially as compared to the results obtained
in Test 1. Furthermore, in Test 3, after operation for
15   about 24 hours, the pressure drop across the wetted
stainless steel wool filter element was about 10 percent
higher than that measured in Tests 1 and 2. The increased
pressure drop indicates that collected bentonite clay
particles were not being removed from the wetted filter
20   media by the draining liquid as efficiently as compared to
when a negative voltage was applied to the filter element
in Tests 1 and 2.

EXAMPLE 2

This Example demonstrates, among other things, the
25   contribution that an electrostatic charge on the filter
media makes to the removal of collected solid particles
from the filter media, regardless of the polarity of the
electric potential applied to the filter media. The
benefits of selecting the polarity of the electric
30   potential applied to the filter media so as to enhance

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removal of collected solid particles from the filter media are also demonstrated.

The gas cleaning apparatus employed in this Example was substantially the same as that described in Example 1

5   except for the following differences. The layer of stainless steel wool filter media comprised approximately 1.42 kg of fibers having a diameter ranging from about 50 μm to about 150 μm and had a bulk density of about 560.6 kg/m^3. The void fraction calculated for the layer of

10   stainless steel wool was about 0.931. The pressure drop across the dry stainless steel wool filter element was about 0.1 kPa at a gas velocity of 14.2 cm/s.

In all the tests conducted in this Example, the system was operated such that the gas velocity through the

15   stainless steel wool filter media was about 14.2 cm/s and the loading of bentonite clay particles in the gas to be treated was about 353 mg/m^3. The fogging nozzles were operated continuously to obtain a filter element irrigation rate of about 4.1 l/min./m^2. In this Example,

20   liquid waste drained from the housing of the gas cleaning apparatus (0.007 percent solids content) was recirculated to the fogging nozzles for gas humidification and fiber bed irrigation.

The only process variable which was changed in the

25   tests conducted in this Example was the polarity of the direct current voltage applied to the stainless steel wool filter media. In Test 1, a voltage of -20 kv was applied to the stainless steel wool filter media, while in Test 2 the voltage applied to the stainless steel filter media

30   was + 20 kv. During Tests 1 and 2, the current drawn by the direct current power supply was about 0.2 mA.

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In each test, the system was operated for a period of time long enough to establish a steady state pressure drop across the wetted stainless steel wool filter element. In addition, the turbidity of liquid waste draining directly from the filter element was periodically determined using a calibrated turbidity meter (H.F. Scientific, Fort Myers, Florida, U.S.A., Model DRT 15CE). The turbidity of the liquid drained from the housing of the gas cleaning apparatus was also measured. The results for Tests 1 and 2 are summarized in Tables 2 and 3, respectively, below. In the following Tables, the measured turbidity is given in nephelometric turbidity units (NTU) and is linearly related to the concentration of insoluble solid particles in the liquid waste.

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TABLE 2

Test 1 - 20 kv	
Steady State Pressure Drop Across Wetted Filter Element	1.38 kPa
System Pressure Drop	7.16 kPa
Filter Element Drain Rate	150 cm³/min.
Housing Drain Turbidity	98.8 NTU
Liquid Waste Sample	NTU
A	14.70
B	11.80
C	10.40
D	11.40
E	11.20
F	10.70
G	10.10
H	8.89
I	9.92
J	9.21
K	9.34
L	10.27
Average Liquid Waste Turbidity	10.7

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TABLE 3

Test 2 + 20 kv	
Steady State Pressure Drop Across Wetted Filter Element	1.59 kPa
System Pressure Drop	7.95 kPa
Filter Element Drain Rate	187 cm^3/min.
Housing Drain Turbidity	97.8 NTU
Liquid Waste Sample	NTU
A	19.60
B	11.30
C	9.62
D	9.05
E	9.10
F	8.20
G	7.51
H	7.10
I	7.55
J	7.85
K	7.41
L	7.95
Average Liquid Waste Turbidity	9.4

The steady state pressure drop across the wetted
filter element increased about 15 percent when the
polarity of the potential applied to the stainless steel

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filter media was switched from negative (Test 1) to
positive (Test 2). Also, the turbidity of the liquid
waste drained from the filter element decreased from Test
1 to Test 2. These results suggest that collected

5   bentonite clay particles accumulated in the stainless
steel filter media to a greater extent when the electric
potential applied to the filter media was positive. It is
believed that bentonite clay particles collected in the
negatively charged filter media were more easily removed

10   from the filter media by the draining liquid due to the
effects of electrophoresis. Nevertheless, these results
demonstrate, that it is possible to practice the process
of the present invention without exercising the preferred
mode of operation, although with an increase in operating

15   cost due to the higher pressure drop across the filter
element.

EXAMPLE 3

This Example demonstrates, among other things, the
use of a woven carbon fiber fabric as the electrically

20   conductive filter media in the wet electrostatic
filtration system of the present invention.

In this and the following Examples, a gas cleaning
apparatus similar to that shown in Fig. 2 was employed.

A woven carbon fiber fabric comprised of fibers

25   having a diameter of about 8 μm (Taconic, Fort Fairfield,
Maine, U.S.A., style TCWG-136, 8.2 oz/yd^2, 3K carbon
filament, weave 2x2 twill) was used as the electrically
conductive filter media. The filter element was
constructed by first wrapping a conventional wire mesh pad

30   as a reentrainment control layer onto a cylindrical,
perforated support screen having an outside diameter of

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about 8.9 cm and a height of about 30.5 cm. The mesh pad
comprised stainless steel fibers having a fiber diameter
of about 280 μm. The woven carbon fiber fabric was then
wound around the support screen in contact with the

5   exterior surface of the mesh pad to obtain an overall
thickness (woven carbon fabric + mesh pad) of
approximately 2.5 cm. The woven carbon fabric/mesh pad
composite had a bulk density of about 240.3 kg/m³. The
pressure drop across the dry woven carbon fabric/mesh pad

10   composite was about 0.15 kPa at a gas velocity of 20.8
cm/s. The filter element was installed in the housing of
the gas filtration apparatus shown in Fig. 2 such that the
distance separating the upstream surface of the carbon
fiber fabric and the ground screen was about 7.6 cm. In

15   accordance with the preferred embodiment of the present
invention, the filter element was connected to the
negative terminal of the direct current power supply such
that a negative potential could be applied to the carbon
fiber filter media.

20   In all the tests conducted in this Example, the
system was operated such that the gas velocity through the
woven carbon fabric/mesh pad composite was about 20.8 cm/s
and the loading of bentonite clay particles in the gas to
be treated was about 110 mg/m³. The fogging nozzles were

25   operated continuously to obtain a filter element
irrigation rate of about 6.1 l/min./m². Liquid waste
drained from the housing of the gas cleaning apparatus
(0.04 percent solids content) was recirculated to the
fogging nozzles for gas humidification and fiber bed

30   irrigation.

         The only process variable which was changed in the
tests conducted in this Example was the direct current

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voltage applied to the woven carbon fabric/mesh pad
composite. In Test 1, a voltage of -20 kv was applied to
the filter media, while in Test 2 the power supply was
turned off.

5   In each test, the system was operated for a period of
time long enough to establish a steady state pressure drop
of about 2.1 kPa across the wetted woven carbon
fabric/mesh pad composite. In addition, samples of the
gas to be treated and of the clean gas were drawn from the
10   gas sampling ports and directed to the associated inertial
impactor to determine particle concentrations in the gas
streams and fractional collection performance of the gas
cleaning apparatus. The conventional gravimetric analysis
technique has limitations because bentonite clay is
15   hygroscopic and achieving a controlled dryness to
determine the weight change in a conventional inertial
impactor stage plate is difficult. Therefore, a wet
insoluble sampling method was developed to better quantify
fractional collection efficiency. This method included
20   washing each stage plate of the inertial impactor with a
known volume of deionized water and then measuring the
turbidity of the resulting wash using the calibrated
turbidity meter used in Example 2. This data was then
used to calculate the mass of insoluble particles
25   collected in that stage. The results of this analysis are
summarized below in Table 4.

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TABLE 4

Particle Diameter (µm)	Inlet Conc. (mg/m³)	Test 1 -20 kv		Test 2 0 kv	
		Exit Conc. (mg/m³)	Collection Efficiency (%)	Exit Conc. (mg/m³)	Collection Efficiency (%)
≥ 7.61	50.320	0.061	99.88	0.071	99.86
< 7.61 ≥ 4.82	5.541	0.002	99.98	0.002	99.96
< 4.82 ≥ 3.20	5.651	0.002	99.98	0.002	99.96
< 3.20 ≥ 2.25	3.674	0.001	99.98	0.002	99.94
< 2.25 ≥ 1.43	4.760	0.003	99.94	0.006	99.87
< 1.43 ≥ 0.73	5.295	0.015	99.71	0.020	99.62
< 0.73 ≥ 0.43	2.711	0.029	99.06	0.044	98.39
< 0.43 ≥ 0.27	0.558	0.022	96.71	0.034	93.89
< 0.27	0.357	0.126	67.89	0.315	11.65
Total	78.865	0.259	99.70	0.496	99.37

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It is noted that the performance of the woven carbon fabric/mesh pad composite is somewhat inferior to that of a stainless steel wool filter element due to the much higher pressure drop required to attain comparable
5   collection efficiency of submicron size particles. Nevertheless, this material of construction is feasible and may have application in corrosive environments where special metal alloy fibers may be marginal.

                            EXAMPLE 4

10   This Example demonstrates, among other things, the benefits of the preferred embodiment of the process of the present invention in which the polarity of the electric potential applied to the filter media is selected so as to enhance removal of collected solid particles from the
15   filter media by electrophoresis. More particularly, with respect to bentonite clay particles which exhibit a negative zeta potential when contacted with tap water, the present Example demonstrates the lower pressure drop across the wetted filter element and other beneficial
20   effects obtained when a negative direct current voltage is applied to the filter media.

     The same gas cleaning apparatus employed in Example 3, including the woven carbon fabric/mesh pad composite filter element, was used in this Example. The system was
25   operated such that the gas velocity through the woven carbon fabric/mesh pad composite was about 20.8 cm/s and the loading of bentonite clay particles in the gas to be treated was about 110 mg/m^3. The fogging nozzles were operated continuously to obtain a filter element
30   irrigation rate of about 6.1 l/min./m^2. Liquid waste drained from the housing of the gas cleaning apparatus

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(0.04 percent solids content) was recirculated to the
fogging nozzles for gas humidification and fiber bed
irrigation.

The system was first operated with a direct current

5   voltage of -20 kv applied to the filter media for a period
of time long enough to establish a steady state pressure
drop of about 1.5 kPa across the wetted woven carbon
fabric/mesh pad composite. These results are shown in
Fig. 6. In Fig. 6, the normalized pressure drop (Co),

10   defined as the ratio of the pressure drop across the
wetted filter element in kPa to the gas velocity in cm/s,
is plotted as a function of time. After about 3 days of
continuous steady state operation, the direct current
voltage applied to the woven carbon fabric/mesh pad

15   composite was switched from - 20 kv to about + 16.5 kv.
Thereafter, operation of the system was continued with a
positive electric potential applied to the filter media
for about 7 days. As shown in Fig. 6, the switch in the
polarity of the voltage applied to the filter media was

20   accompanied by a step increase in the normalized pressure
drop. Furthermore, after the polarity of the electric
potential applied to the filter media was switched, the
normalized pressure drop across the wetted filter element
steadily increased and never reached a steady state value.

25   These results demonstrate the benefits of the preferred
embodiment of the process of the present invention in
which the polarity of the electric potential applied to
the filter media is selected such that the charge on the
filter media is the same as the surface charge on the

30   insoluble solid particles collected in the wetted filter
media. It is believed that by practicing the preferred
embodiment of the process of the present invention,

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insoluble particles of bentonite clay collected in the
wetted woven carbon fabric/mesh pad filter media were
repulsed from the surfaces of the filter media and thereby
more easily removed by the draining liquid such that a
5 stable pressure drop across the filter element could be
maintained.

                        EXAMPLE 5

      This Example demonstrates, among other things, the
effect of the diameter of stainless steel fibers used as
10 the electrically conductive filter media has on the
collection efficiency and pressure drop of the wet
electrostatic filtration system of the present invention.
      In Test 1, the filter element was constructed by
first wrapping a conventional wire mesh pad as a
15 reentrainment control layer onto a cylindrical, perforated
support screen having an outside diameter of about 8.9 cm
and a height of about 30.5 cm. The mesh pad comprised
stainless steel fibers having a fiber diameter of about
280 μm and the reentrainment control layer was about 1.3
20 cm thick. Stainless steel wool comprised of fibers having
a fiber diameter from about 50 μm to about 150 μm was then
wound around the support screen in contact with the
exterior surface of the mesh pad to obtain an overall
thickness (stainless steel wool + mesh pad) of
25 approximately 4.0 cm. The stainless steel wool/mesh pad
composite had a bulk density of about 352.4 kg/m^3. The
pressure drop across the dry stainless steel wool/mesh pad
composite was about 0.05 kPa at a gas velocity of 20.3
cm/s. The filter element was installed in the housing of
30 the gas filtration apparatus such that the distance

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separating the upstream surface of the layer of stainless
steel wool and the ground screen was about 6.4 cm.

In the filter element used in Test 2, a courser
stainless steel wool comprised of fibers having a fiber

5   diameter from about 90 μm to about 300 μm was substituted
for the stainless steel wool used in the filter element of
Test 1. The thickness of the stainless steel wool/mesh
pad composite in the filter element used in Test 2 was
about 3.4 cm and had a bulk density of about 320.4 kg/m^3.

10   The pressure drop across the dry stainless steel wool/mesh
pad composite used in Test 2 was about 0.02 kPa at a gas
velocity of 20.3 cm/s. The filter element was installed
in the housing of the gas filtration apparatus such that
the distance separating the upstream surface of the layer

15   of stainless steel wool and the ground screen was about
6.7 cm.

In both Tests 1 and 2, the filter element was
connected to the negative terminal of the direct current
power supply and a negative direct current voltage of

20   about - 20 kv was applied to the stainless steel wool
filter media. The system was operated such that the gas
velocity through the stainless steel wool/mesh pad
composite was about 20.3 cm/s. The fogging nozzles were
operated continuously to obtain a filter element

25   irrigation rate of about 0.41 l/min./m^2. Liquid waste
drained from the housing of the gas cleaning apparatus
(0.04 percent solids content) was recirculated to the
fogging nozzles for gas humidification and fiber bed
irrigation. In addition, the filter element irrigation

30   rate was increased to about 4.1 l/min./m^2 once every 24
hours for a period of about 30 minutes. In Test 1, the
loading of bentonite clay particles in the gas to be

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treated was about 110 mg/m³, while in Test 2 the loading

of bentonite clay particles in the gas to be treated was

about 73 mg/m³.

     In Tests 1 and 2, the system was first operated for a

5   period of time long enough to establish a steady state

pressure drop across the wetted stainless steel wool/mesh

pad composite of about 0.09 kPa and about 0.07 kPa,

respectively. Samples of the gas to be treated and of the

clean gas were drawn from the gas sampling ports and

10 directed to the associated inertial impactor while the

system was operated at the low filter element irrigation

rate. The particle concentrations in the gas streams and

fractional collection performance of the gas cleaning

apparatus was determined using the wet insoluble sampling

15 method described in Example 3. The results for Tests 1

and 2 are summarized below in Tables 5 and 6,

respectively.

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TABLE 5

Test 1 - Fine Stainless Steel Wool			
Particle Diameter (μm)	Inlet Conc. (mg/m³)	Exit Conc. (mg/m³)	Collection Efficiency (%)
≥ 7.61	60.361	0.036	99.94
< 7.61 ≥ 4.82	5.576	0.003	99.95
< 4.82 ≥ 3.20	6.420	0.003	99.95
< 3.30 ≥ 2.25	4.068	0.004	99.91
< 2.25 ≥ 1.43	4.703	0.014	99.71
< 1.43 ≥ 0.73	5.493	0.069	98.75
< 0.73 ≥ 0.43	2.514	0.061	97.57
< 0.43 ≥ 0.27	0.535	0.023	95.78
< 0.27	0.359	0.034	90.50
Total	90.030	0.246	99.73

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TABLE 6

Test 2 - Course Stainless Steel Wool			
Particle Diameter (μm)	Inlet Conc. (mg/m^3)	Exit Conc. (mg/m^3)	Collection Efficiency (%)
$\geq$ 7.61	46.413	0.028	99.87
< 7.61 $\geq$ 4.82	5.110	0.001	99.83
< 4.82 $\geq$ 3.20	5.212	0.001	99.88
< 3.30 $\geq$ 2.25	3.389	0.002	99.83
< 2.25 $\geq$ 1.43	4.390	0.010	99.61
< 1.43 $\geq$ 0.73	4.884	0.045	98.57
< 0.73 $\geq$ 0.43	2.500	0.053	97.34
< 0.43 $\geq$ 0.27	0.515	0.025	94.22
< 0.27	0.329	0.112	58.18
Total	72.743	0.277	99.44

The increase in the diameter of the stainless steel
wool filter media from Test 1 to Test 2 was accompanied by
a decrease in the submicron particle collection
efficiency. This is as expected and is in agreement with
5   the known theories of gas particle separation. In the
practice of the present invention, the benefits of using
finer diameter fibers in the filter media must be balanced
against increased sensitivity to particle loading which
may necessitate more frequent intermittent washing at a
10   higher irrigation rate and potentially shorter life span
in corrosive environments. The selection of fiber

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diameter in view of these various considerations will vary
from application to application and is well understood by
those skilled in the art.

EXAMPLE 6

5   This Example demonstrates, among other things, the
effect of the gas velocity has on the collection
efficiency of the wet electrostatic filtration system of
the present invention.

        The same gas cleaning apparatus employed in Test 1 of
10   Example 5, including the fine stainless steel wool/mesh
pad composite filter element, was used in this Example.

        In both Tests 1 and 2, the filter element was
connected to the negative terminal of the direct current
power supply and a negative direct current voltage of
15   about - 24 kv was applied to the stainless steel wool
filter media. The filter element was irrigated as
described above in Example 5. In Test 1, the loading of
bentonite clay particles in the gas to be treated was
about 90 mg/m³ and the system was operated such that the
20   gas velocity through the stainless steel wool/mesh pad
composite was about 20.3 cm/s. In Test 2, the loading of
bentonite clay particles in the gas to be treated was
about 75 mg/m³ and the gas velocity through the stainless
steel wool/mesh pad composite was increased to about 25.4
25   cm/s. In Tests 1 and 2, the system was first operated for
a period of time long enough to establish a steady state
pressure drop across the wetted stainless steel wool/mesh
pad composite of about 0.09 kPa and about 0.1 kPa,
respectively. Samples of the gas to be treated and of the
30   clean gas were drawn from the gas sampling ports and
directed to the associated inertial impactor while the

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system was operated at the low filter element irrigation
rate. The particle concentrations in the gas streams and
fractional collection performance of the gas cleaning
apparatus was determined using the wet insoluble sampling
method described in Example 3. The results for Tests 1
and 2 are summarized below in Tables 7 and 8,
respectively.

TABLE 7

Test 1 - 20.3 cm/s Gas Velocity			
Particle Diameter (μm)	Inlet Conc. (mg/m^3)	Exit Conc. (mg/m^3)	Collection Efficiency (%)
≥ 7.61	60.361	0.008	99.99
< 7.61 ≥ 4.82	5.576	0.002	99.97
< 4.82 ≥ 3.20	6.420	0.001	99.98
< 3.30 ≥ 2.25	4.068	0.001	99.98
< 2.25 ≥ 1.43	4.703	0.001	99.97
< 1.43 ≥ 0.73	5.493	0.001	99.98
< 0.73 ≥ 0.43	2.514	0.003	99.88
< 0.43 ≥ 0.27	0.535	0.003	99.51
< 0.27	0.359	0.031	91.43
Total	90.030	0.051	99.94

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TABLE 8

Test 2 - 25.4 cm/s Gas Velocity			
Particle Diameter (μm)	Inlet Conc. (mg/m³)	Exit Conc. (mg/m³)	Collection Efficiency (%)
≥ 7.61	50.012	0.017	99.97
< 7.61 ≥ 4.82	4.620	0.004	99.91
< 4.82 ≥ 3.20	5.319	0.005	99.91
< 3.30 ≥ 2.25	3.371	0.004	99.88
< 2.25 ≥ 1.43	3.897	0.008	99.80
< 1.43 ≥ 0.73	4.551	0.044	99.04
< 0.73 ≥ 0.43	2.083	0.052	97.50
< 0.43 ≥ 0.27	0.443	0.020	95.43
< 0.27	0.298	0.034	88.43
Total	74.594	0.189	99.75

The increase in the gas velocity through the stainless steel wool/mesh pad composite from Test 1 to Test 2 was accompanied by a decrease in the submicron particle collection efficiency. This is also expected and is in agreement with the known theories of gas particle separation.

EXAMPLE 7

This Example demonstrates, among other things, the use of a metal and polymeric fiber co-knit material as the

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electrically conductive filter media in the wet
electrostatic filtration system of the present invention.

A co-knit material (ACS Industries, Houston, Texas,
U.S.A., Catalog No. 8TMW11) was employed as the
5   electrically conductive filter media. The co-knit
material was made from a continuous, Alloy 20 stainless
steel wire (wire diameter of about 280 μm) and a woven
TEFLON filament (fiber diameter of about 15μm to about 30
μm). The filter element was constructed by winding the
10   co-knit material onto a cylindrical, perforated support
screen having an outside diameter of about 8.9 cm and a
height of about 30.5 cm. The resulting layer of
electrically conductive filter media was substantially
uniform having a thickness of approximately 3.4 cm and a
15   bulk density of about 224.3 kg/m^3. The void fraction
calculated for the layer of co-knit material was 0.968.
The filter element was installed in the housing of the gas
filtration apparatus such that the distance separating the
upstream surface of the layer of co-knit material and the
20   ground screen was about 6.7 cm. The pressure drop across
the dry co-knit material was about 0.025 kPa at a gas
velocity of 25.4 cm/s.

The filter element was connected to the negative
terminal of the direct current power supply and a negative
25   direct current voltage of about -20 kv was applied to the
co-knit material filter media. The system was operated
such that the gas velocity through the co-knit material
filter media was about 25.4 cm/s. The fogging nozzles
were operated continuously to obtain a filter element
30   irrigation rate of about 0.41 l/min./m^2. Liquid waste
drained from the housing of the gas cleaning apparatus
(0.04 percent solids content) was recirculated to the

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fogging nozzles for gas humidification and filter element
irrigation. In addition, the filter element irrigation
rate was increased to about 4.1 l/min./m² once every 24
hours for a period of about 30 minutes. The loading of
5   bentonite clay particles in the gas to be treated was
maintained constant at about 42 mg/m³.

The system was first operated for a period of time
long enough to establish a steady state pressure drop
across the wetted layer of co-knit material of about 0.07
10   kPa. Samples of the gas to be treated and of the clean
gas were drawn from the gas sampling ports and directed to
the associated inertial impactor while the system was
operated at the low filter element irrigation rate. The
particle concentrations in the gas streams and fractional
15   collection performance of the gas cleaning apparatus was
determined using the wet insoluble sampling method
described in Example 3. The results are summarized below
in Table 9.

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TABLE 9

Co-Knit Material, -20 kv			
Particle Diameter (μm)	Inlet Conc. (mg/m³)	Exit Conc. (mg/m³)	Collection Efficiency (%)
$\geq$ 6.27	18.23	0.0283	99.85
< 6.27 $\geq$ 3.97	1.985	0.0035	99.90
< 3.97 $\geq$ 2.63	1.667	0.0035	99.81
< 2.63 $\geq$ 1.85	1.017	0.0016	99.84
< 1.85 $\geq$ 1.17	1.275	0.0035	99.82
< 1.17 $\geq$ 0.59	1.335	0.0141	98.98
< 0.59 $\geq$ 0.34	0.6180	0.0177	97.10
< 0.34 $\geq$ 0.21	0.1554	0.0106	93.19
< 0.21	0.1624	0.0283	82.51
Total	26.44	0.1095	99.59

These results clearly demonstrate the technical feasibility of using a metal and polymeric fiber co-knit material as electrically conductive filter media in the practice of the present invention. The co-knit material

5   combines a low dry pressure drop with a collection efficiency comparable to that achieved in the preceding examples using other materials as the filter media. The use of a metal and polymeric fiber co-knit material as the electrically conductive filter media is preferred in

10 corrosive environments (e.g., treatment of acid mist-containing effluents) where a material cost advantage may

be realized as compared to a filter media comprised solely
of corrosion-resistant, high alloy metal fibers. It
should be further noted that in the construction of this
co-knit material, a continuous metal wire is employed.

5 Therefore, in spite of the presence of the woven TEFLON
filament, the voltage applied to the co-knit material is
distributed uniformly over the filter media.

In view of the above, it will be seen that the
several objects of the invention are achieved. As various

10 changes could be made in the above-described processes and
apparatus without departing from the scope of the
invention, it is intended that all matter contained in the
above description be interpreted as illustrative and not
in a limiting sense.

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WHAT IS CLAIMED IS:

1.   A process for treating a gas stream to remove
solid or liquid particles entrained in the gas stream, the
process comprising:
        providing a substantially electrically isolated, gas-
5   permeable filter element comprising electrically
conductive filter media wetted with a liquid;
        electrostatically charging the wetted filter media by
applying an electric potential to the filter media with
respect to ground;
10   passing the gas stream to be treated through an
electric field imposed by a limited current discharge
between the electrostatically charged filter media and a
ground electrode to induce a charge on particles entrained
in the gas having a polarity opposite of the charge on the
15 filter media;
        passing the gas stream containing charged particles
through the filter element with a horizontal component of
movement, the entrained particles thereby being captured
in the wetted filter media to produce a clean gas stream
20 from which entrained particles have been removed; and
        continuously draining the liquid from the wetted
filter media under the force of gravity to remove captured
particles and produce a liquid waste stream exiting the
filter element containing the removed particles, the
25 draining liquid having a horizontal component of movement
through the filter media toward the downstream surface of
the filter element relative to the direction of gas flow
through the filter element imparted by the gas drag force.

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2. A process as set forth in claim 1 wherein the liquid wetting the filter media is aqueous.

3. A process as set forth in claim 2 further comprising contacting the gas stream to be treated with a spray of aqueous liquid droplets upstream of the filter element relative to the direction of gas flow, aqueous
5   liquid droplets thereby being entrained in the gas to be treated, the entrained liquid droplets being captured in and wetting the filter media with aqueous liquid as the gas passes through the filter element.

4. A process as set forth in claim 3 wherein the spray of liquid droplets has a mean droplet diameter of greater than about 20 μm.

5. A process as set forth in claim 1 further comprising controlling reentrainment of the draining liquid and captured particles in the clean gas stream, the process further comprising passing the clean gas stream
5   through reentrainment control means disposed downstream of the filter media relative to the direction of gas flow through the filter element.

6. A process as set forth in claim 1 wherein the electric potential is applied to the filter media by connecting the filter media to a direct current power supply.

7. A process as set forth in claim 6 wherein the electric potential is applied to the filter media continuously.

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8. A process as set forth in claim 7 wherein the electric potential applied to the filter media is substantially maintained at a magnitude just below that which would result in spark over between the filter
5   element and the ground electrode at the prevailing operating conditions.

9. A process as set forth in claim 6 wherein the electric potential is applied to the filter media intermittently.

10. A process as set forth in claim 6 wherein the magnitude of the electric potential applied to the filter media is at least about 10 kv.

11. A process as set forth in claim 10 wherein the magnitude of the electric potential applied to the filter media is from at least about 10 kv to about 70 kv.

12. A process as set forth in claim 11 wherein the limited current discharge between the electrostatically charged filter media and the ground electrode per unit of gas flow area of the filter element is no greater than
5   about 10 mA/m^2.

13. A process as set forth in claim 1 wherein solid particles are entrained in the gas to be treated, solid particles captured within the wetted filter media and the liquid wetting the filter media forming a suspension
5   having a zeta potential characterized by a charge of the same polarity attached to the surface of a predominant number of captured solid particles within the suspension,

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the polarity of the electric potential applied to the
filter media being selected such that the filter media has
10   a charge of the same polarity as the zeta potential of the
suspension, captured solid particles in the suspension
thereby being repulsed from the filter media by
electrophoresis to enhance removal of captured solid
particles from the wetted filter media by the draining
15   liquid.

14.   A process for treating a gas stream to remove
solid particles entrained in the gas stream, the process
comprising:
providing a substantially electrically isolated, gas-
5   permeable filter element comprising electrically
conductive filter media wetted with a liquid;
electrostatically charging the wetted filter media by
applying an electric potential to the filter media with
respect to ground;
10   passing the gas stream containing solid particles
through the filter element with a horizontal component of
movement, the entrained particles thereby being captured
in the wetted filter media to produce a clean gas stream
from which entrained particles have been removed; and
15   continuously draining the liquid from the wetted
filter media under the force of gravity to remove captured
particles and produce a liquid waste stream exiting the
filter element containing the removed particles, the
draining liquid having a horizontal component of movement
20   through the filter media toward the downstream surface of
the filter element relative to the direction of gas flow
through the filter element imparted by the gas drag force,
captured solid particles and the liquid wetting the filter

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media forming a suspension having a zeta potential

25   characterized by a charge of the same polarity attached to
the surface of a predominant number of captured solid
particles within the suspension, the polarity of the
electric potential applied to the filter media being
selected such that the filter media has a charge of the

30   same polarity as the zeta potential of the suspension,
captured solid particles in the suspension thereby being
repulsed from the filter media by electrophoresis to
enhance removal of captured solid particles from the
wetted filter media by the draining liquid.

15.   A process set forth in claim 14 wherein the
suspension contains captured solid particles having a
positive charge attached to the surface of the particle
and captured solid particles having a negative charge

5   attached to the surface of the particle, the polarity of
the electric potential applied to the filter media being
periodically switched to cause captured solid particles
having a positive charge attached to the surface of the
particle and captured solid particles having a negative

10   charge attached to the surface of the particle within the
suspension to be alternately repulsed from the filter
media.

16.   A process set forth in claim 15 wherein the
proportion of captured solid particles in the suspension
having a positive charge attached to the surface of the
particle and the proportion of captured solid particles in

5   the suspension having a negative charge attached to the
surface of the particle is from about 30 percent to about
70 percent.

17. A process as set forth in claim 16 wherein the period during which the charge on the filter media is of a selected polarity is proportional to the fraction of captured solid particles in the suspension having a charge

5   of the same polarity attached to the surface of the particle.

18. An apparatus for treating a gas stream to remove solid or liquid particles entrained in the gas stream and produce a clean gas stream from which particles have been removed and a liquid waste stream containing particles

5   removed from the gas stream, the apparatus comprising:

a housing having an inlet for introducing the gas stream into the housing, an outlet for discharging the clean gas stream from the housing and a liquid drain port for removing the liquid waste from the housing;

10   a substantially electrically isolated, gas-permeable filter element comprising electrically conductive filter media wetted by a liquid, the filter element being disposed and oriented within the housing such that the gas stream introduced into the housing is forced to pass

15   through the filter element with a horizontal component of movement and liquid continuously drains from the wetted filter media under the force of gravity to remove particles captured in the filter media and produce the liquid waste stream containing the removed particles;

20   a ground electrode disposed within the housing and connected to ground;

a direct current power supply; and

means for connecting the direct current power supply to the filter media and the ground electrode such that an

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25   electric potential is applied to the filter media with
      respect to ground to electrostatically charge the filter
      media.

         19.   An apparatus as set forth in claim 18 wherein
      the direct current power supply includes automatic voltage
      control means, the automatic voltage control means
      substantially maintaining the electric potential applied
5   to the filter media at a magnitude just below that which
      would result in spark over between the filter element and
      the ground electrode at the prevailing operating
      conditions within the apparatus.

         20.   An apparatus as set forth in claim 18 wherein
      the direct current power supply includes control means
      which allows the polarity of the electric potential
      applied to the filter media to be selectively reversed
5   without having to disconnect the filter media from the
      power supply.

         21.   An apparatus as set forth in claim 18 wherein
      the liquid wetting the filter media is aqueous, the
      apparatus further comprising means for contacting the gas
      stream with a spray of aqueous liquid droplets upstream of
5   the filter element relative to the direction of gas flow.

         22.   An apparatus as set forth in claim 21 wherein
      liquid spray contacting means comprises a fogging nozzle
      in selective fluid communication with a source of liquid.

         23.   An apparatus as set forth in claim 18 wherein
      the electrically conductive filter media comprises a

material selected from the group consisting of woven metal

fibers, non-woven metal fibers, woven fabrics comprising

5   carbon or metal-coated polymeric fibers and co-knit

materials comprising a mixture of electrically conductive

and electrically insulative fibers.

24.   An apparatus as set forth in claim 23 wherein

the electrically conductive filter media comprises a non-

woven mat of stainless steel fibers comprised of fibers

having a diameter ranging from about 40 μm to about 500

5   μm.

25.   An apparatus as set forth in claim 24 wherein

the void fraction of the electrically conductive filter

media is greater than about 80 percent.

26.   An apparatus as set forth in claim 23 wherein

the electrically conductive filter media comprises a co-

knit material comprising metal fibers and polymeric

fibers.

27.   An apparatus as set forth in claim 18 wherein

the filter element further comprises reentrainment control

means disposed downstream of the electrically conductive

filter media relative to the direction of gas flow through

5   the filter element.

28.   An apparatus as set forth in claim 18 wherein

the filter element is in the form of a substantially

vertical cylinder suspended within the housing, the filter

element comprising a cylindrical foraminous support upon

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5   which the electrically conductive filter media is
    supported.

    29.   An apparatus as set forth in claim 18 wherein
    the ground electrode is made integral with the housing,
    the interior surface of the housing serving as the ground
    electrode.

    30.   An apparatus as set forth in claim 29 wherein
    the housing is made from an electrically insulative,
    corrosion-resistant material and the ground electrode
    comprises a static dissipative plastic coating on the
5   interior surface of the housing, the static dissipative
    plastic coating having a resistivity of no more than about
    1×10^4 ohm·cm.

    31.   An apparatus for treating a gas stream to remove
    solid or liquid particles entrained in the gas stream and
    produce a clean gas stream from which particles have been
    removed and a liquid waste stream containing particles
5   removed from the gas stream, the apparatus comprising:
            a housing in the form of a vertical cylinder having
    an inlet for introducing the gas stream into the housing,
    an outlet for discharging the clean gas stream from the
    housing and a liquid drain port for removing the liquid
10 waste from the housing;
            a substantially electrically isolated, gas-permeable
    filter element and seal leg combination suspended within
    the housing, the gas-permeable filter element in the form
    of a substantially vertical cylinder and comprising
15 electrically conductive filter media wetted by a liquid
    and supported upon a cylindrical foraminous support, the

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filter element being disposed and oriented within the
housing such that the gas stream introduced into the
housing is forced to pass through the filter element with
20   a horizontal component of movement to remove particles
entrained in the gas stream and produce the clean gas
stream and liquid continuously drains from the wetted
filter media under the force of gravity to remove
particles captured in the filter media and produce the
25   liquid waste stream containing the removed particles, the
seal leg comprising a liquid drain conduit and seal leg
cup, the liquid waste stream being removed from the filter
element through the liquid drain conduit and collecting in
the seal leg cup to provide a liquid seal in the liquid
30   drain conduit and prevent the gas stream introduced into
the housing from bypassing the filter media;

means for contacting the gas stream with a spray of
liquid droplets upstream of the filter element relative to
the direction of gas flow;
35.   a ground electrode connected to ground, the ground
electrode made integral with the housing, the interior
surface of the housing serving as the ground electrode;

a direct current power supply; and

means for connecting the direct current power supply
40   to the filter media and the ground electrode such that an
electric potential is applied to the filter media with
respect to ground to electrostatically charge the filter
media.

32.   An apparatus as set forth in claim 31 further
comprising a clean gas conduit, the outlet of the housing
being in fluid communication with the interior of the
filter element through the clean gas conduit, the clean

5   gas conduit being joined to the housing and to the filter
element such that the filter element and seal leg
combination is suspended within the housing from the clean
gas conduit, the clean gas conduit and filter element
being in coaxial relationship with the housing such that
10   an annular gap separates the interior surface of the
housing from the exterior surface of the clean gas
conduit.

33.   An apparatus as set forth in claim 32 further
comprising means for introducing a purge gas into the
annular gap separating the interior surface of the housing
from the exterior surface of the clean gas conduit.

34.   An apparatus as set forth in claim 31 wherein
the housing is made from an electrically insulative,
corrosion-resistant material and the ground electrode
comprises a static dissipative plastic coating on the
5   interior surface of the housing, the static dissipative
plastic coating having a resistivity of no more than about
1×10^4 ohm·cm.

35.   An apparatus as set forth in claim 31 wherein
the means for connecting the direct current power supply
to the ground electrode comprises an electrically
conductive grounding lug extending into the housing into
5   contact with the ground electrode.

36.   An apparatus as set forth in claim 35 wherein a
multiplicity of electrically conductive grounding lugs
extending into the housing into contact with the ground

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electrode are uniformly distributed over the surface of

5   the housing.

        37.   A modular gas cleaning system for treating a gas

stream to remove solid or liquid particles entrained in

the gas stream and produce a clean gas stream from which

particles have been removed and a liquid waste stream

5   containing particles removed from the gas stream, the

system comprising:

        at least one gas cleaning apparatus module, the

module comprising a housing, a substantially electrically

isolated gas-permeable filter element and seal leg

10   combination suspended within the housing and a ground

electrode, the housing in the form of a vertical cylinder

having an inlet for introducing the gas stream into the

housing, an outlet for discharging the clean gas stream

from the housing and a liquid drain port for removing the

15   liquid waste from the housing, the gas-permeable filter

element in the form of a substantially vertical cylinder

and comprising electrically conductive filter media wetted

by a liquid and supported upon a cylindrical foraminous

support, the filter element being disposed and oriented

20   within the housing such that the gas stream introduced

into the housing is forced to pass through the filter

element with a horizontal component of movement to remove

particles entrained in the gas stream and produce the

clean gas stream and liquid continuously drains from the

25   wetted filter media under the force of gravity to remove

particles captured in the filter media and produce the

liquid waste stream containing the removed particles, the

seal leg comprising a liquid drain conduit and seal leg

cup, the liquid waste stream being removed from the filter

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30   element through the liquid drain conduit and collecting in
     the seal leg cup to provide a liquid seal in the liquid
     drain conduit and prevent the gas stream introduced into
     the housing from bypassing the filter media, the ground
     electrode connected to ground and being made integral with

35   the housing, the interior surface of the housing serving
     as the ground electrode;

          means for contacting the gas stream with a spray of
     liquid droplets upstream of the filter element relative to
     the direction of gas flow;

40   a direct current power supply;

          means for connecting the direct current power supply
     to the filter media and the ground electrode such that an
     electric potential is applied to the filter media with
     respect to ground to electrostatically charge the filter

45   media; and

          an intake manifold and a clean gas manifold adapted
     for connection to at least one module, the intake manifold
     and the clean gas manifold being connected to the module
     such that the intake manifold and the clean gas manifold

50   are in fluid communication through the module, the gas
     stream being introduced into the intake manifold and
     passed through the module, the clean gas stream from the
     module being discharged from the system through the clean
     gas manifold, the intake manifold serving as a sump for

55   collecting liquid waste draining from the module.

          38.   A system as set forth in claim 37 wherein the
     intake manifold and the clean gas manifold are adapted for
     connection to a variable number of modules such that the
     system is capable of accommodating varying gas flow

5   capacity demands, the system comprising at least two

modules, the intake manifold and the clean gas manifold
being connected to the modules such that the intake
manifold and the clean gas manifold are in fluid
communication through the modules, the gas stream being

10 introduced into the intake manifold and distributed
between the modules by the intake manifold and the clean
gas stream from the modules being collected in the clean
gas manifold and discharged from the system, the intake
manifold serving as a universal sump for collecting liquid

15 waste draining from the modules, the filter media within
the modules being connected to the direct current power
supply in parallel.

39. A system as set forth in claim 38 wherein the
electrical connection between the filter media in the
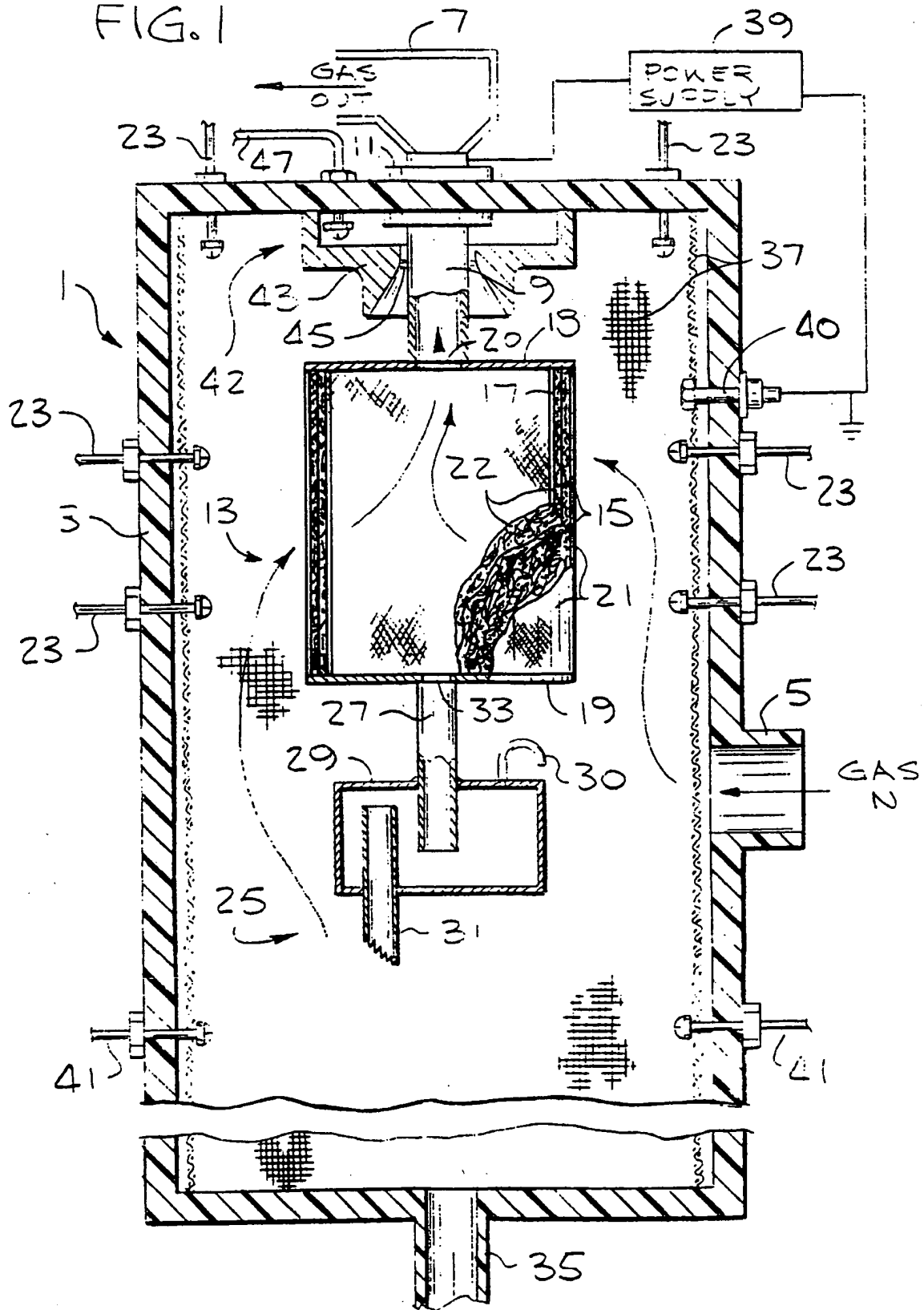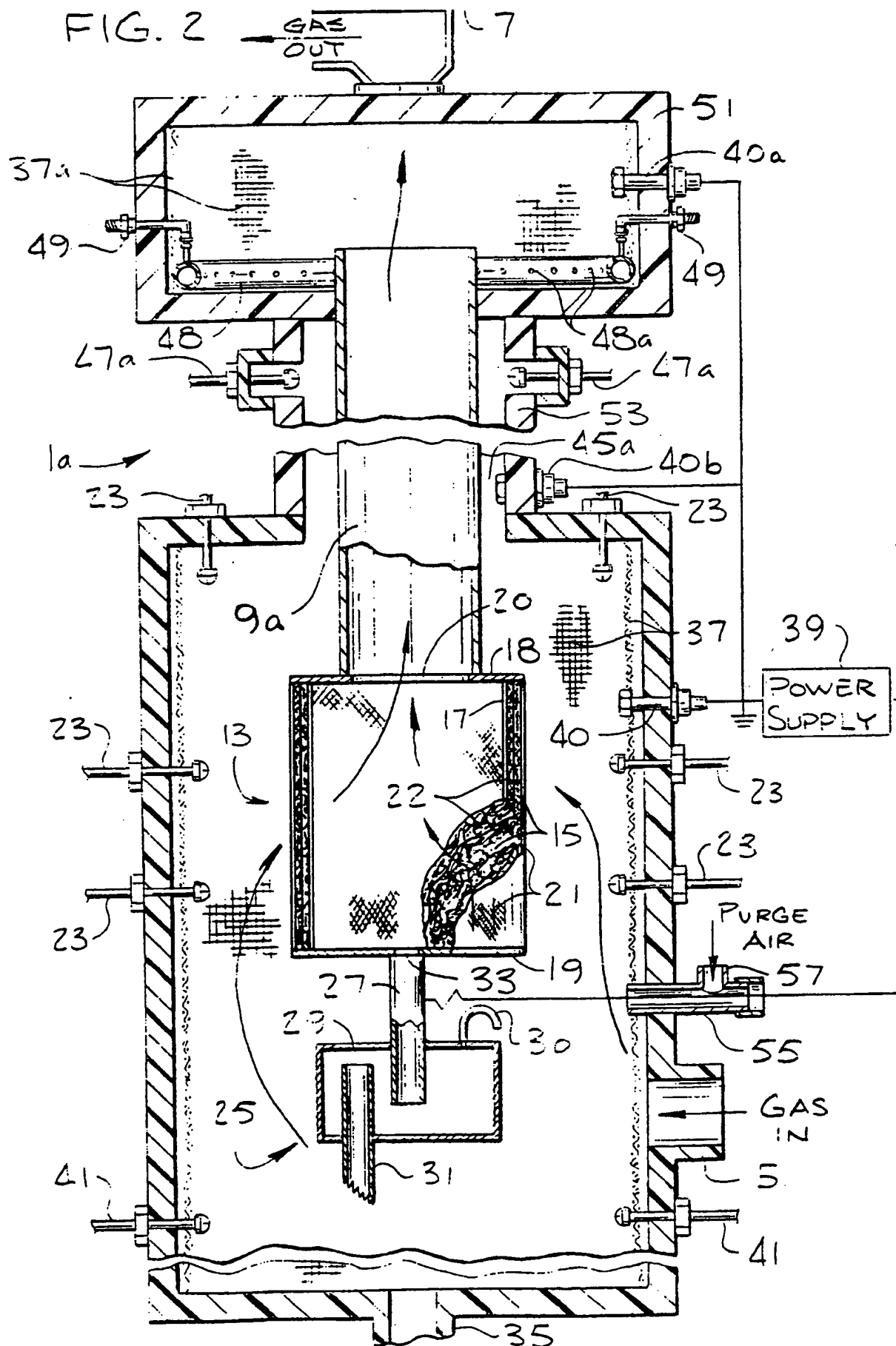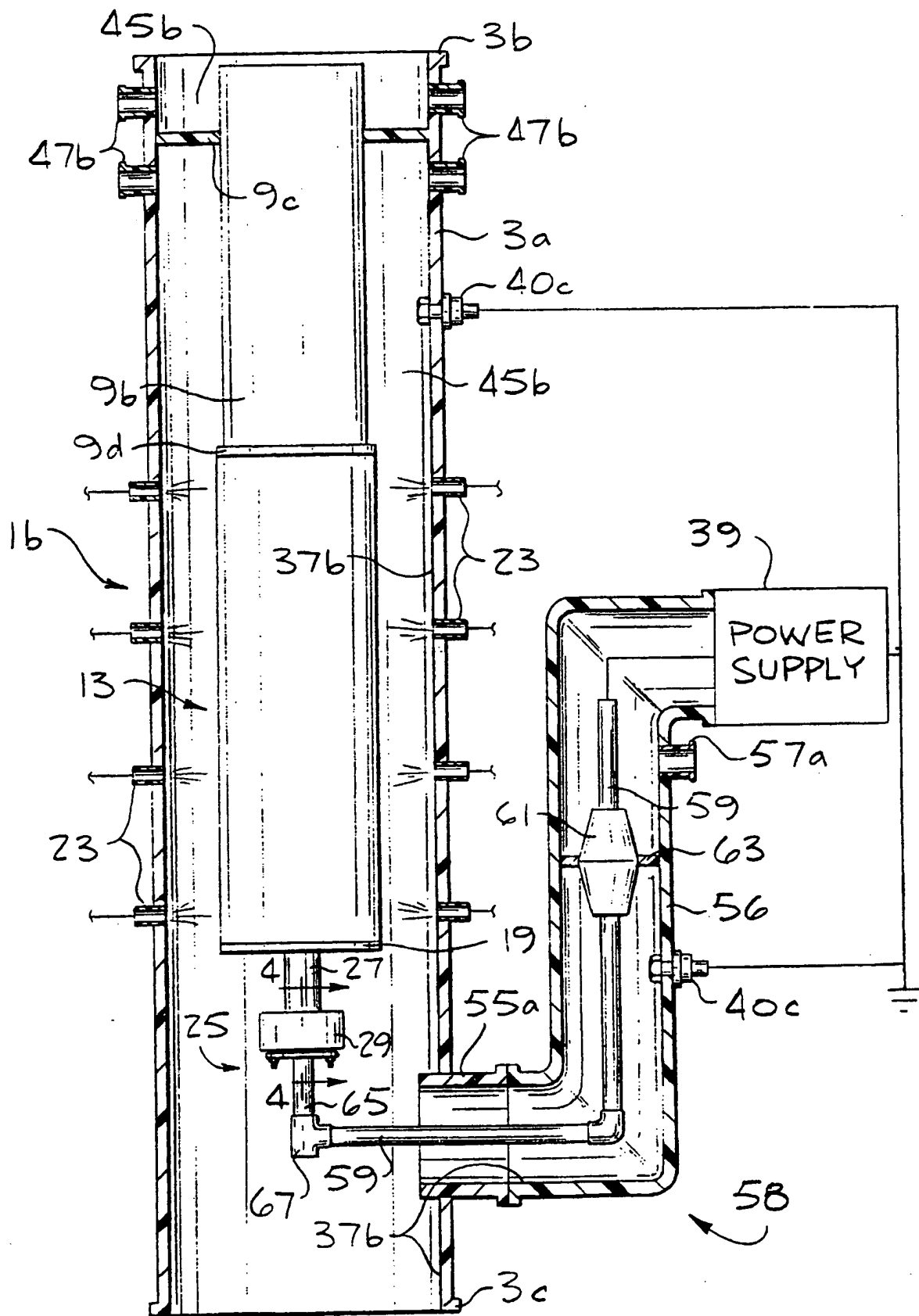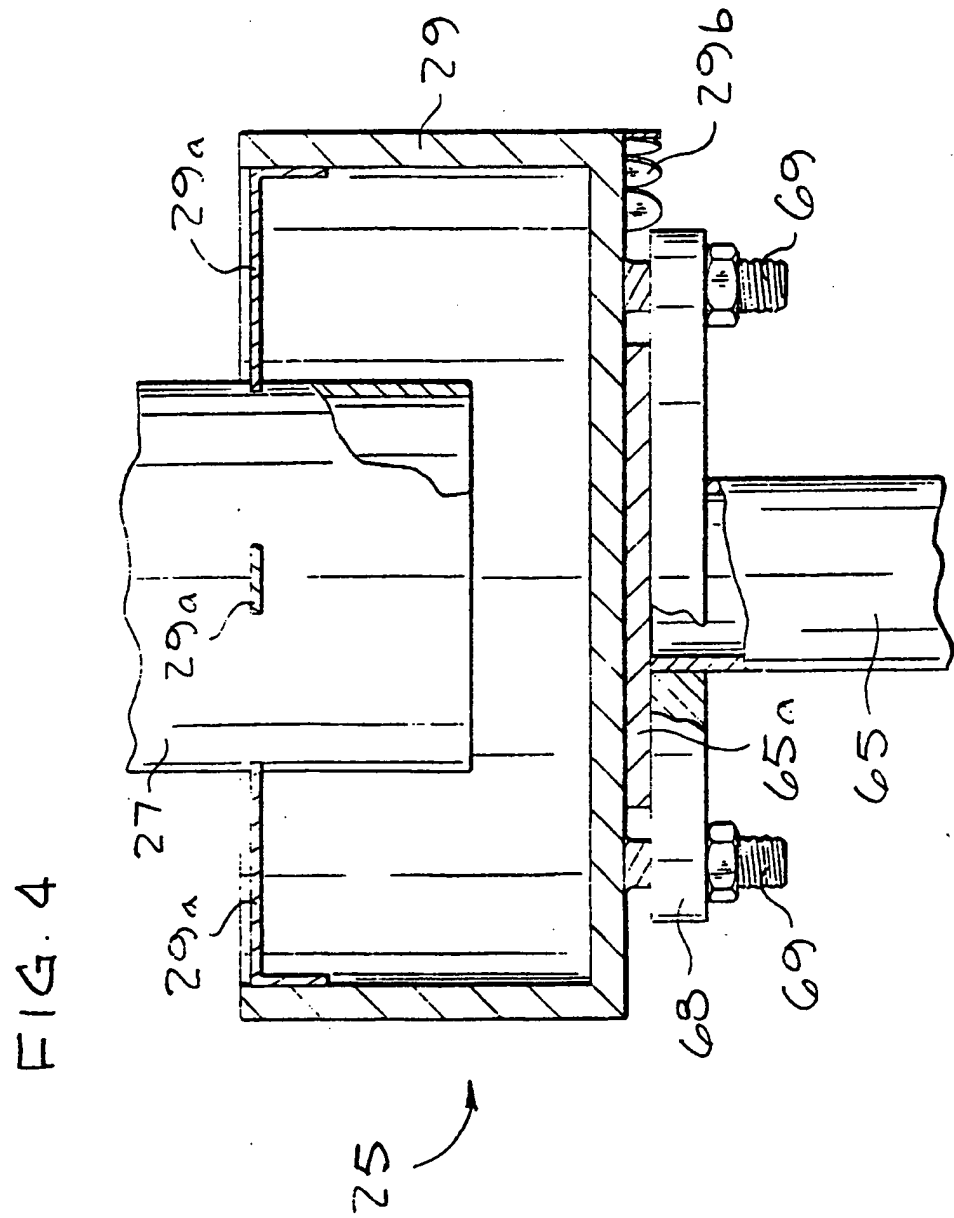modules passes through the intake manifold.

FIG.1

FIG. 2   → GAS OUT   7
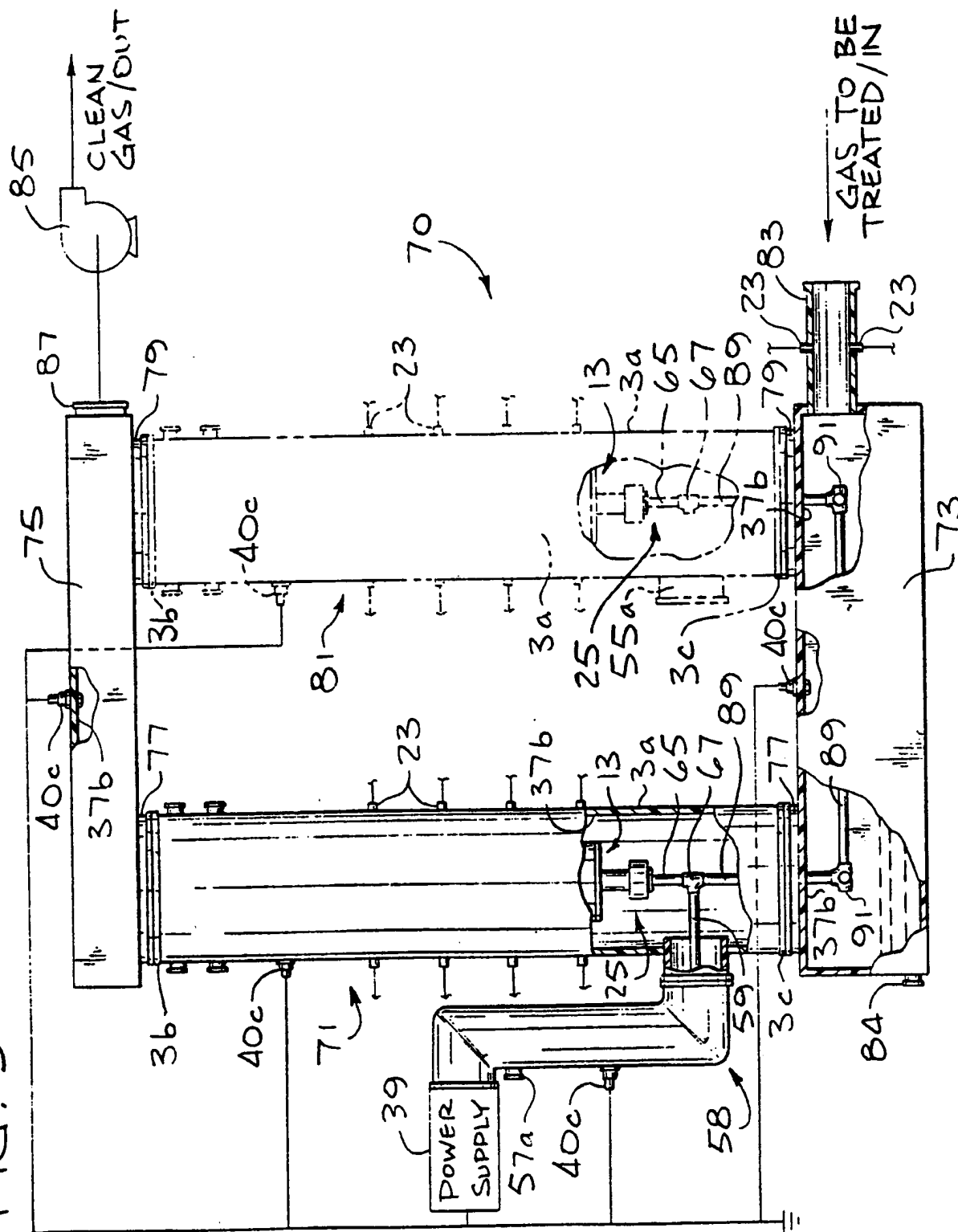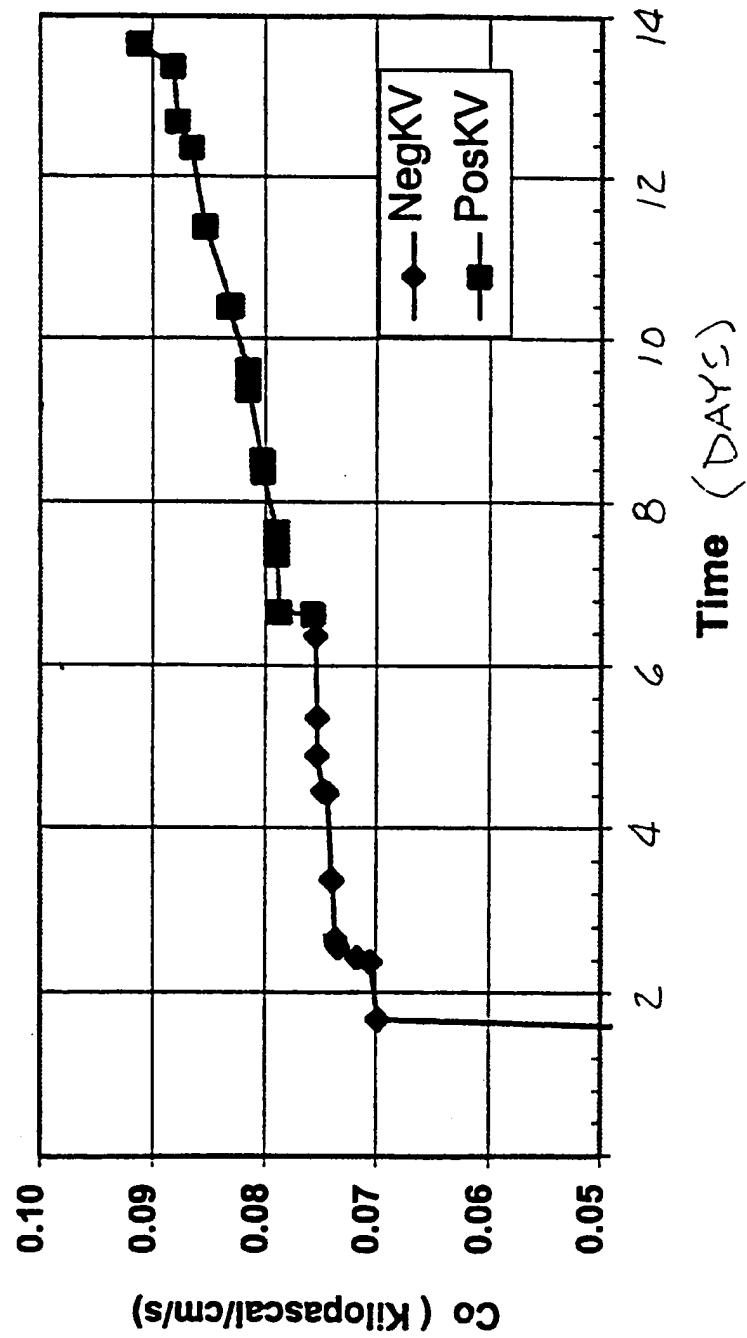
51

37a

49

48   48a

47a   47a

40a

49

53

45a   40b

1a

23   23

9a

20

18

17

37

40

39

POWER SUPPLY

23

13

22

15

21

23   23

27   33   19

29   30

25

31

41   41

35

23

PURGE AIR   57

55

GAS IN   5

FIG. 3

POWER
SUPPLY

FIG. 4

FIG. 5

CLEAN GAS/OUT

GAS TO BE TREATED/IN

POWER SUPPLY

FIG.6

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   B03C3/16   B03C3/53

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   B03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 392 723 A (ARTAMA ARVI) 29 December 1978	1-3,6,7, 10-14, 18,20, 21,23
	see page 4, line 11 - page 7, line 5; claims 1,3; figures 1-4 ---	
Y	US 4 619 670 A (MALCOLM DAVID H ET AL) 28 October 1986	1,2
A	see column 5, line 7 - column 6, line 37	3,4,6,7, 10,11, 13-15, 18, 20-22, 28,29, 37,38
	see column 7, line 29 - line 55; claims 1,4; figures 1-3,6 --- -/--	

| [X] | Further documents are listed in the continuation of box C. | [X] | Patent family members are listed in annex. |

° Special categories of cited documents :

"A" document defining the general state of the art which is not
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     which is cited to establish the publication date of another
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     other means
"P" document published prior to the international filing date but
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     or priority date and not in conflict with the application but
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"X" document of particular relevance; the claimed invention
     cannot be considered novel or cannot be considered to
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     ments, such combination being obvious to a person skilled
     in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 June 1999	25/06/1999

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1

page 1 of 2

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category '	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Inter nal Application No
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